Fluvial → Lacustrine Transition Zones of the Passaic Formation, Newark Basin: The Role of Anastomosed Fluvial Depositional Systems.

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1. Abstract

The sediments within the Newark Basin contain a record of cyclic deposition at multiple frequencies. Due to their pronounced cyclicity and climatic sensitivity the lacustrine deposits within the basin have been the focus of many basin studies. While the lake deposits are well documented, relatively little is known about the fluvial systems that carried water and sediments to these ancient lakes. Locally, fluvial sediments can be coarse- grained and channelized, and are believed to represent deposition in coarse-grained braided systems, notably in the Stockton and Passaic. Such deposits can be limited to areas proximal to the main border fault system and were noted for this project in the Pebbles Bluff exposure of the LM Member of the Passaic Formation. However, there are many relatively fine-grained, thin-bedded sandy fluvial deposits that show little evidence for channeling and amalgamation. Rather, these systems are predominantly aggradational. The system evolves through nodal avulsion and the construction of crevasse and terminal splays. Outcrop observations of the Metlars and Livingston Members of the Passaic Formation show that the non-lacustrine, relatively coarser grained facies are dominated by extensive tabular sandsheets whose geometries, structures and range of grain sizes are consistent with deposition in anastomosed fluvial networks, similar to those of the Okavango Delta in Botswana. The Okavango lies within a half-graben in the southernmost extension of the East African Rift system. Paleogeographic reconstructions, using paleomagnetic and paleoclimatic data taken from lacustrine deposits, have placed the Newark Basin at roughly 20° north latitude during the late Triassic and early Jurassic, which is similar in climate to the 20° south latitude position of the present-day Okavango. As such, the Okavango may serve as a general analog for the fluvial members of the Passaic Formation in terms of hydrology and architectural evolution.

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3. Introduction/ Background

The Newark Rift Basin is one of many Mesozoic rift basins associated with the break up of the supercontinent of Pangea. Rifting lasted ~30 million years and left behind tracts of extensional rift basins that stretch from the Gulf of Mexico through the eastern United States, Greenland, Norway, Western Europe, and Morocco (Olsen 1997). The study of these basins has led to a greater understanding of global climatic changes throughout the middle Triassic to early Jurassic.

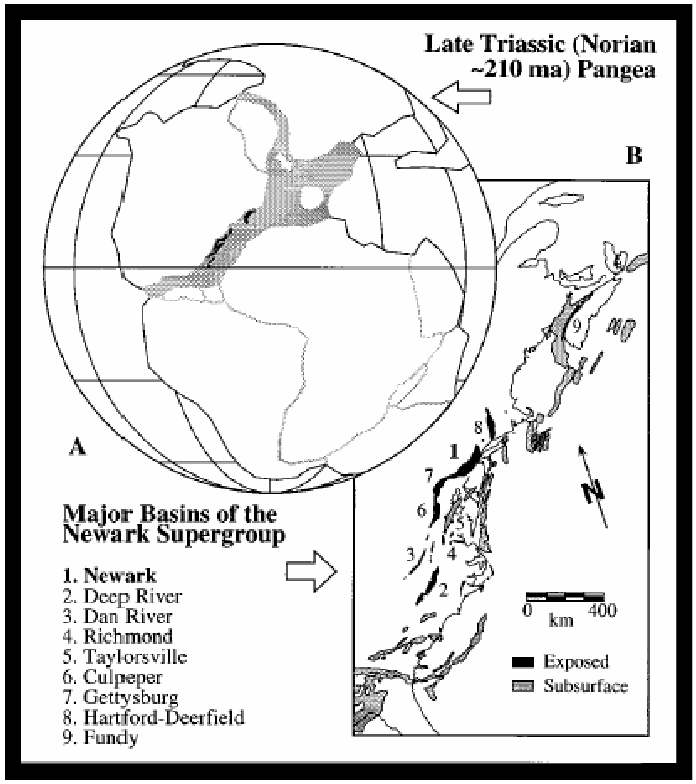


Figure 1 Olsen et al. 1996

The sediments deposited within these basins leave a record of paleomagnetism and paleoclimatic change. The Newark Basin is perhaps the best understood of all of the Mesozoic basins. It's location and numerous exposures make it the focal point for rift basin stratigraphic study. It is located along the U.S eastern seaboard spanning the border of New Jersey, Pennsylvania and New York. The basin is bisected by the Delaware River, resulting in numerous high quality exposures.

The Newark Basin has been studied for over 130 years (Olsen et al. 1996) and was the subject of a National Science Foundation effort to recover cores from nearly the entire Triassic portion of the basin. The Newark Basin Coring Project (NBCP) has recovered nearly 7000 m of continuous core including the Stockton, Lockatong, and Passaic Formations. These cores provide a wealth of data concerning the Newark Basin and its structural and climatic evolution.

3.1 Newark Stratigraphy

The largest packages within the Newark, and all other contemporaneous basins world wide, are tectonostratigraphic sequences. These are sequences that are bound top and bottom by major unconformities and are the result of significant changes in the rate of basin extension (Olsen, 1997). There are 4 recognized tectonostratigraphic sequences (T.S.) (fig. 2) within Mesozoic basins but only T.S. III sequence is present in the Newark. These sequences are further

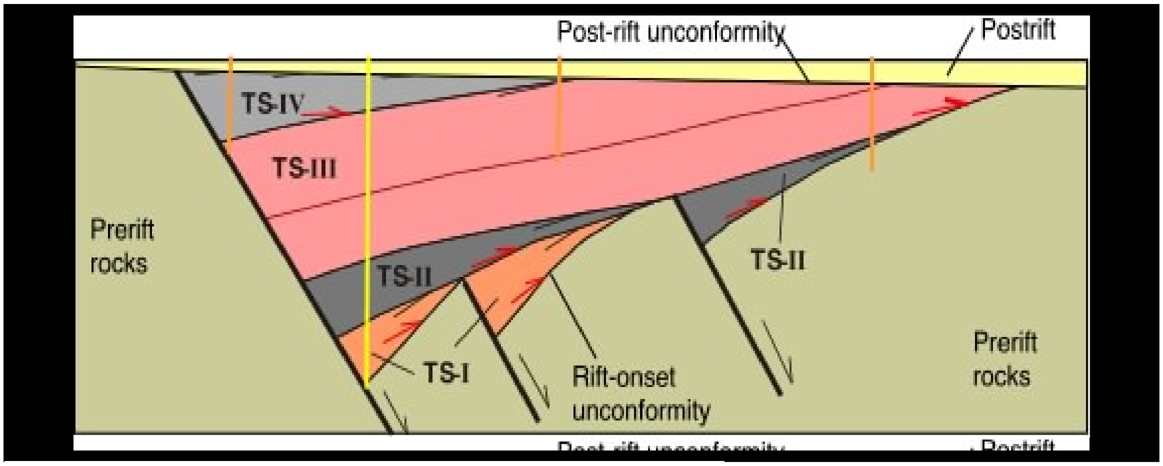


Figure 2 Schlische & Withjack

divided into formations based upon the dominant type of sedimentary deposits. The Triassic portion of the basin is divided into three main formations. The basal Stockton Formation is ~1800 m thick and is of Middle Carnian → Late Carnian age (219 – 213 mya). It is made up of mostly coarse brown, fine red, and very minor gray fluvial & alluvial clastic sediments. The overlying Lockatong is ~1100m thick and Late Carnian age (225 mya), The Lockatong is dominated by gray and black deep-water lacustrine deposits. The cyclical record of lake level rise and fall and has been the focus of many studies. The fluvial component of the Lockatong is minor in comparison. The Passaic Formation is ~ 3300 m thick and is of Late Carnian → Hettangian age (206 – 225 mya). It is made up of alternating sediments that are of both lacustrine and fluvial origin. The Orange Mountain Basalt is associated with the Central Magmatic Igneous Province (CAMP) (Olsen, 1997) tholeittic basalt flows that accompanied certain stage of continental rifting. It is ~150m thick and is Hettangian in age. The lowest Jurassic deposit is the Feltville Formation. It is ~170m thick and is of Hettangian age. Its deposits are mostly red cyclical lacustrine clastic sediments with some gray and black lacustrine sediment. There are also minor red fluvial sandstones and alluvial fan conglomerates. The Preakness Basalt overlies the Feltville and is similar to the Orange Mountain basalt. The Towaco Formation is 340 m of red cyclical lacustrine sediment and is of Hettangian Age (206 – 213 mya). The Hook Mountain Basalt is similar to the previous flows and has been dated to 200-213 mya. The Boonton Formation is the upper most formation. It consists of red cyclical lacustrine sediments with minor fluvial and alluvial fan conglomerates.

The fluvial deposits within the Newark Basin are well documented in the Stockton but only loosely defined in the overlying Passaic Formation. The Stockton was deposited predominantly in a braided to meandering or anastomosing fluvial system (Smoot 1991; Olsen 1996). Braided fluvial deposits do exist in the Passaic, however, most VanHouten cycle deposits that have been identified have not been scrutinized for their fluvial characteristics but rather have served as paleoclimatic markers due to their lacustrine deposits.

My research focuses on the Passaic formation due to its numerous exposures. The Passaic fluvial systems should differ from those of the Stockton for several reasons. First, the geographic location of the Newark Basin did not remain constant throughout rifting. During the late Triassic the continent of

Pangea migrated northward from around the equator to ~20° north of the equator (Kent, Muttoni 2003). This latitudinal drift, and the resulting change in climate should affect the character of both lacustrine and fluvial deposits. Second, the Stockton fluvial source region, which was located to the southeast, consisted of rocks of the hanging wall. In contrast, during Passaic deposition the source region lay to the northwest and consisted of footwall rocks (Olsen 1997). Local evidence for braided streams occurs in the Passaic, but this doesn't account for the large amounts of non-lacustrine, fine-grained sediment found within the coarser grained facies of VanHouten cycle deposits. The ancient record of anastomosed streams is limited. However, there are modern examples of anastomosed streams that share numerous similarities with the conditions that were present during the time of Passaic deposition. Extensive anastomosed plains would probably occupy low gradient subsiding basin floors (Smith, Putnam 1980) much like the present-day Okavango Delta. The Okavango is located in Botswana, southern Africa, in an environment that would apparently mimic the Newark Rift basin region during the late Triassic. The Okavango is thought to reside in an area that is a southern extension of the East Africa Rift Zone and is an area of active sedimentation (McCarthy, Merry 2001). The region is a relatively dry and hot intracontinental local much like the late Triassic Newark Rift setting.

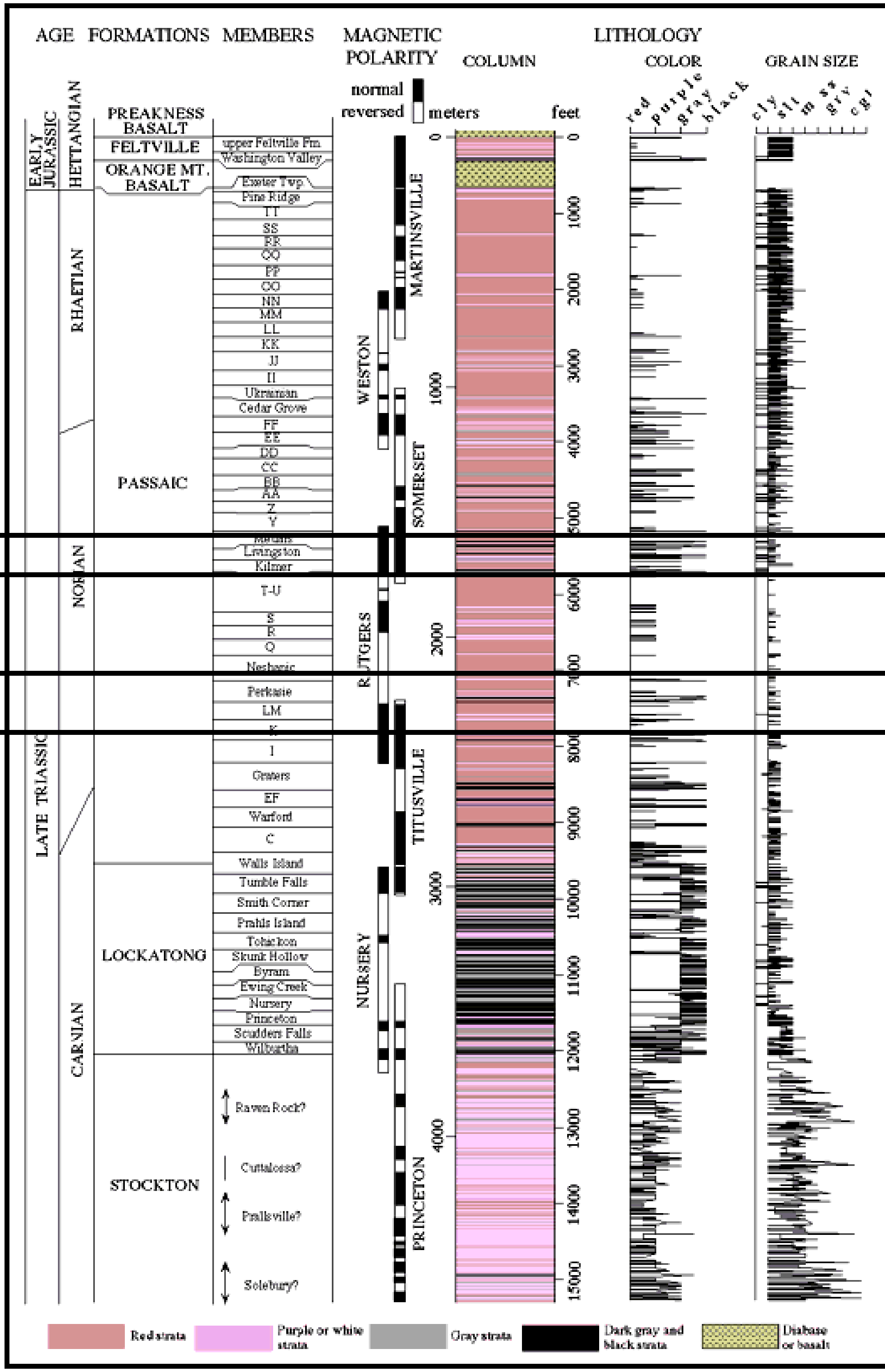


Figure3 Newark Basin stratigraphy**.** Members observed in the field lie within the boxes. Modified from Olsen et al. 1996.

3.2 Lacustrine Cyclicity

The cyclical deposition that is preserved in the lacustrine deposits within the basin is controlled largely by celestial mechanics. This has an effect on temperature and precipitation patterns, which in turn affects the rise and fall of lake levels within the basin that is responsible for the cyclicity exhibited by lake deposits. The Milankovitch cycle that is thought to control all of these processes is the Precession cycle. It is the degree of the earth's axial tilt and is responsible for the fluctuations in the amount of solar energy received by different latitudes

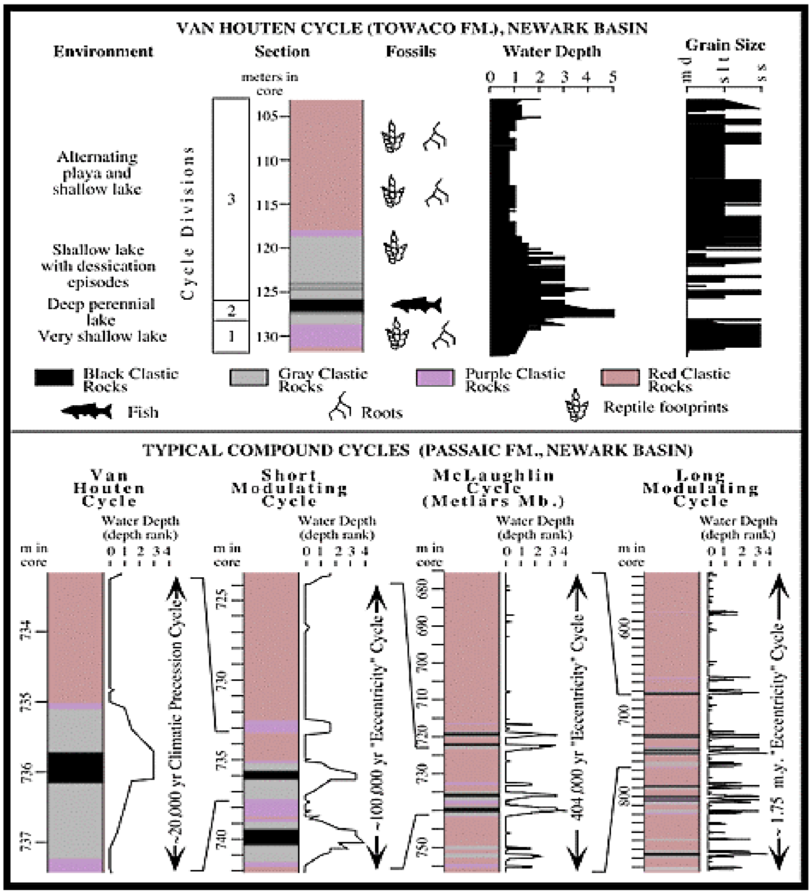


Figure 4 Olsen 1997.

The Van Houten cycle is the smallest of the observable sequences that demonstrates this cyclicity. It consists of 4 to 6 meter thick bundles of sediments that were deposited as result of a relatively quick lake level rise followed by a more gradual transition to shallow lake and fluvial deposits. The fluvial deposits are located in the upper part of these cycles. It is an area of thick-bedded, red sandstones with minor massive mudstones.

The McLaughlin cycles provide the basis for which the major formations are further divided into members (Olsen et al., 1997). It is made up of groups of Van Houten cycles and is itself a vertical record of astronomical forcing. McLaughlin cycles reflect the same general trends as the Van Houten cycles, only on a larger scale.

Two other cycles also figure prominently in the sedimentary record of the basin. The Short and Long Modulating cycles serve to periodically reinforce the climatic changes reflected by the other cycles.

3.3 Fluvial Depositional Systems

Before a discussion of results or presentation of data can begin some background information concerning different fluvial depositional environments must be given.

Braided Systems

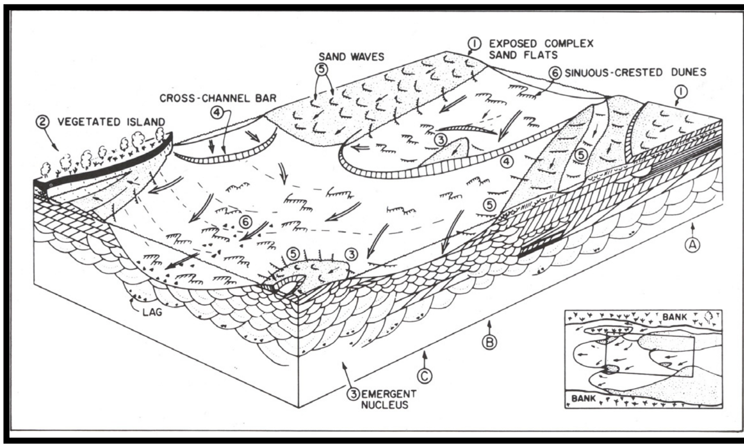


Figure 5 Walker 1984

Figure 6 www.2umt.edu

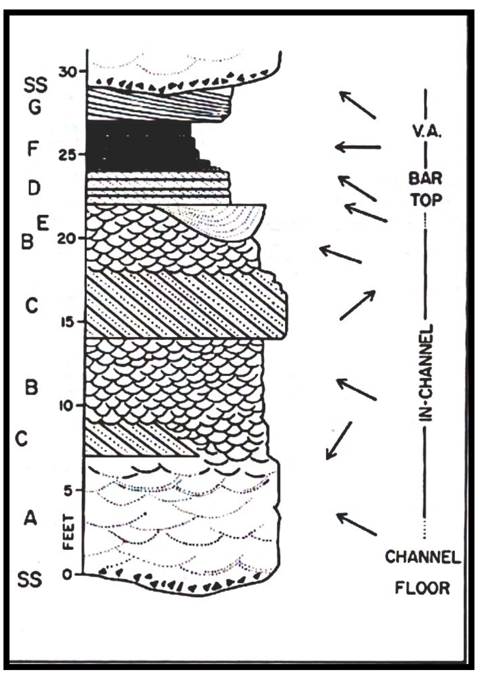


Figure 7 Olsen & Gore 1989

Braided river systems are typically composed of medium to very coarse-grained sediment. The exhibit low sinuosity and are characterized by many channels separated by longitudinal, cross-channel, and transverse bars or small islands. They have high but sporadic water discharge, little vegetation and easily erodable banks. They are best developed in distal parts of alluvial fans, and in mountainous reaches of river systems where slope angles are high and coarse-grained sediment is plentiful (Prothero & Schwab, 1996). Braided stream deposits are characterized by lateral migration of channels and coarse channel fill that fines upward. Due to their unstable banks, lateral channel migration usually reworks any vertically accreted deposits. Deposits are laterally continuous, extensive sandsheets that are unconfined by shales. Any shales that do exist are patchy, laterally discontinuous and ineffective barriers to vertical fluid migration.

Anastomosed Systems

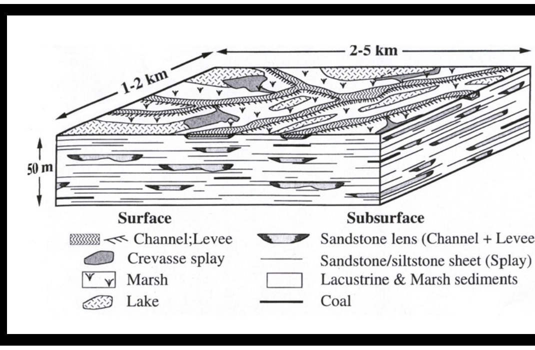


Figure 8 Nadon 1994

Figure 9 www.2umt.edu

Anastomosed river systems differ from braided systems in that they typically deposit much finer -grained sediments. Anastomosed channels have a higher sinuosity, higher bed load/suspended load ratio and a much lower discharge (Q)/ load ratio than do braided systems (Friedmann, 2003). Compared to the unstable bank systems of braided streams, anastomosed rivers have stable banks, which are usually reinforced by complex rooting systems of plant communities. These banks allow the system to aggrade vertically rather than channel processes being dominated by lateral accretion. Both braided and meandering systems have diagnostic channel forms that exhibit sharp basal scour and extensive lateral reworking of previously deposited sediments. Such channel processes do not dominate anastomosed systems. They are identified, in part, by the persistence of multiple, highly sinuous channels, but more important in an anastomosed system is the environment through which these shallow channels flow. The extensive floodplains that contain these systems can be broken down into six sub environments (Smith and Putnam, 1980), which are:

1. **Backswamp** facies consisting of organic silty mud.
2. **Peat Bog** facies, which is composed of variable amounts of organic debris.
3. **Ephemeral Floodpond** facies, which deposit very fine grained laminated and wave rippled lacustrine sediments. Mudcracked exposure surfaces are also common.
4. **Channel** deposits that are shallow, low relief sand lenses. Often contain climbing ripples and planar-crossbeds.
5. **Levee systems** that are made up of variable amounts of organic material.

6. **Crevasse** deposits. These are laterally extensive, tabular sand sheets that can be up to 1 meter thick. These constitute the bulk of the silt → sand size component of anastomosed systems. Contains structures including, climbing current ripples, planar bedding/laminations and wave rippled mud surfaces indicating submergence in shallow water after deposition in deccelerative flow (Naydon, 1994). These deposits also commonly show evidence of exposure such as Mudcracks.

Each of the six subenvironments contains characteristic grain size trends, bed geometries and sedimentary structures that are indicative of its depositional environment.

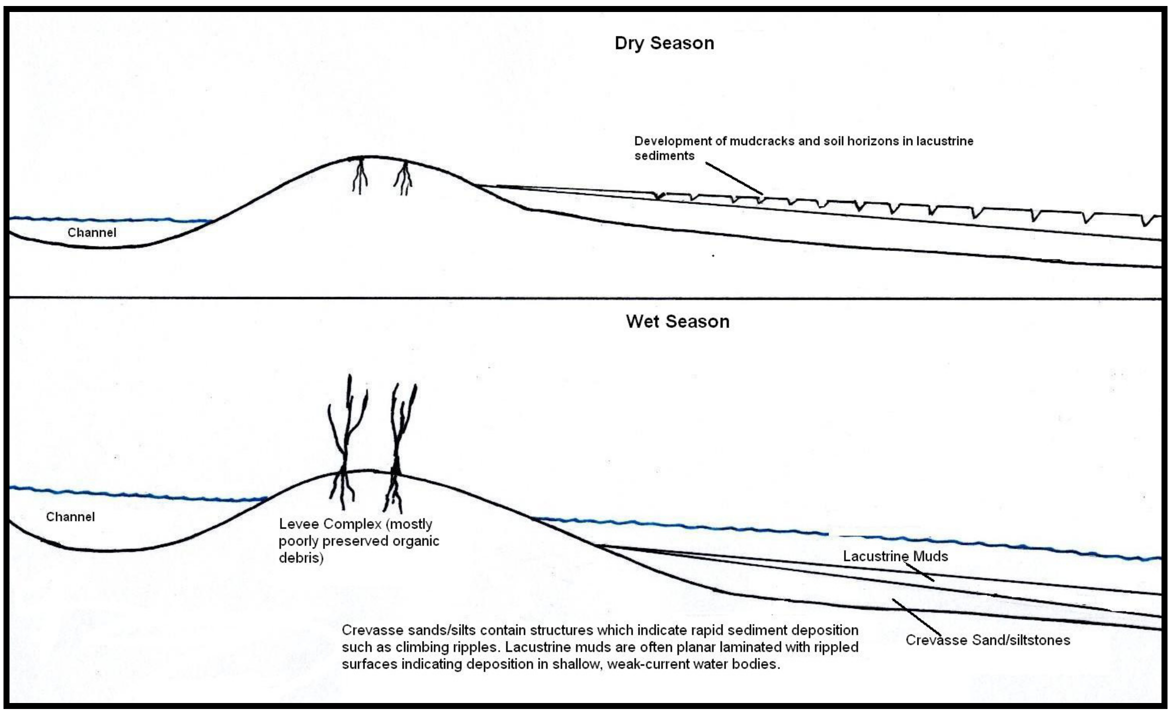


Figure 10 Cross section showing topography of anastomosed facies.

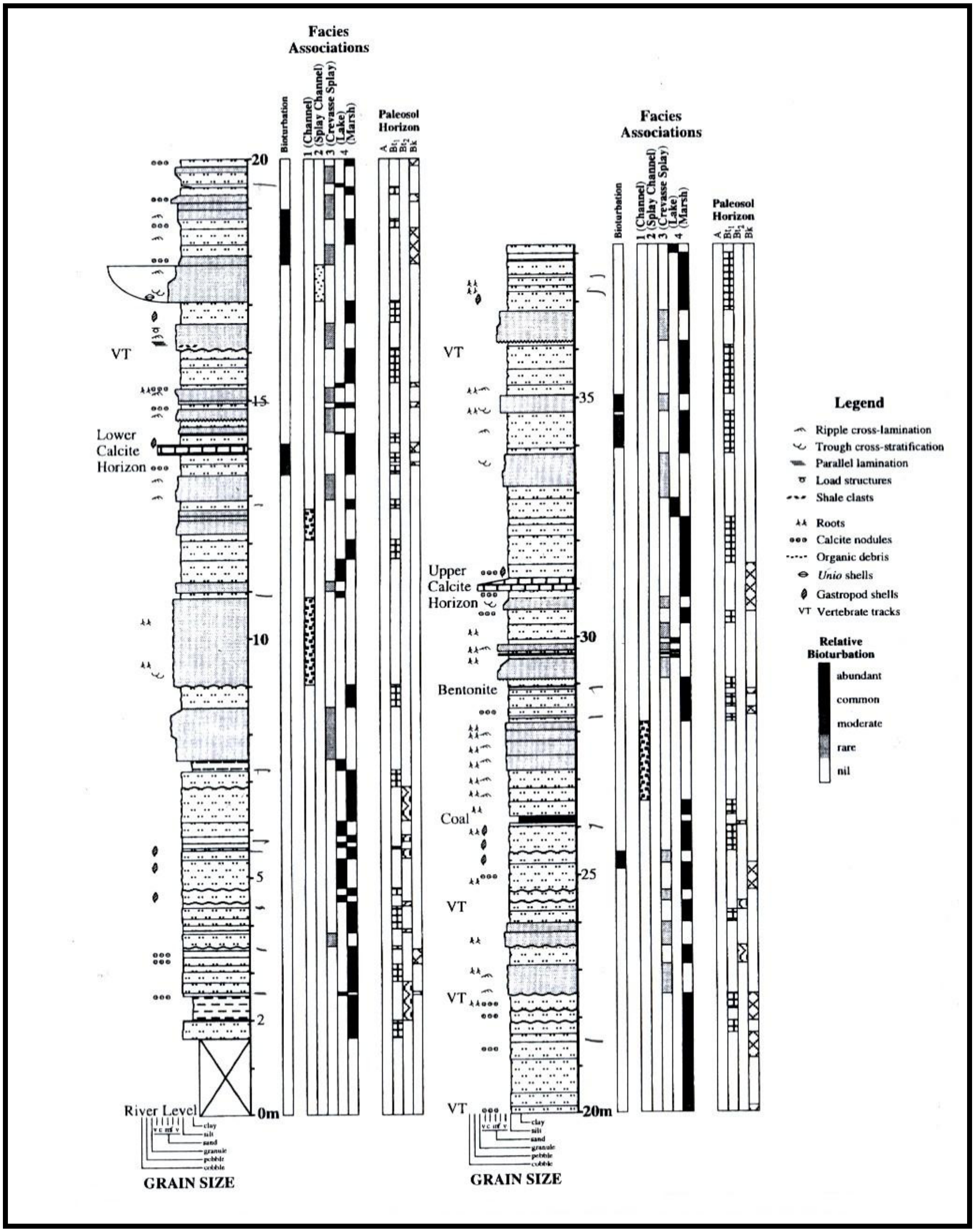


Figure 11 (Nadon, 1994) Anastomosed facies of the St. Mary's River Formation, Alberta Canada

4. Methods of Analysis

This project is predominantly based on the collection of data in the field. Measurements and comparisons are accounted for in the compilation of measured sections, outcrop photographs and field notes. The components themselves are listed and described in detail below including methods of analysis for each. In addition to the significant fieldwork component we also used the cores of the NBCP, which are stored at Rutgers University. The cores have been correlated to the outcrops by previous workers.

4.1 Measured Sections

Measured sections consist of several key components from which information such as flow competency, flow direction, duration of deposition and environmental parameters can be inferred. There are six primary components in the sections:

1. Grain size: The determination of the grain size within a bed gives an indication of the flow velocities that were present during time of deposition. Grain sizes are divided into 10 categories based on size. From the size in micrometers (μm) it is converted into more convenient Phi (Φ) units and then into a relative classification as follows; 62 – 88μm → 4.0 – 3.5 Φ = very fine lower, 88 –125 μm → 3.5 – 3.0 Φ = very fine lower, 125 – 177 μm → 3.0 – 2.5 Φ = fine lower, 177 – 250 μm → 2.5 – 2.0 Φ = fine upper, 250 – 350 μm → 2.0 –1.5 Φ = medium lower, 350 – 500 μm → 1.5 –1.0 Φ = medium upper, 500 – 710 μm → 1.0 - 0.5 Φ = coarse lower, 710 –1000 μm → 0.5 – 0.0Φ = coarse upper, 1000 – 1410 μm → 0.0 – (-) 0.5 Φ = very coarse lower, 1410 – 2000 μm → -0.5 – (-) 1.0 Φ = very coarse upper. These grain sizes are plotted against flow velocities in a Hjulstrom Diagram (fig. 12).

Classification of grain size in the field involves some degree subjectivity. A grain size chart is used which has a graphic representation of each grain size category. These representations are then compared to the grain size of the outcrop taken from each bed and from several locations within each bed. In addition to the interpretation of grain size, the categories themselves have a range of sizes that vary from 37μm up to 590μm.

Hjulstrom Diagram

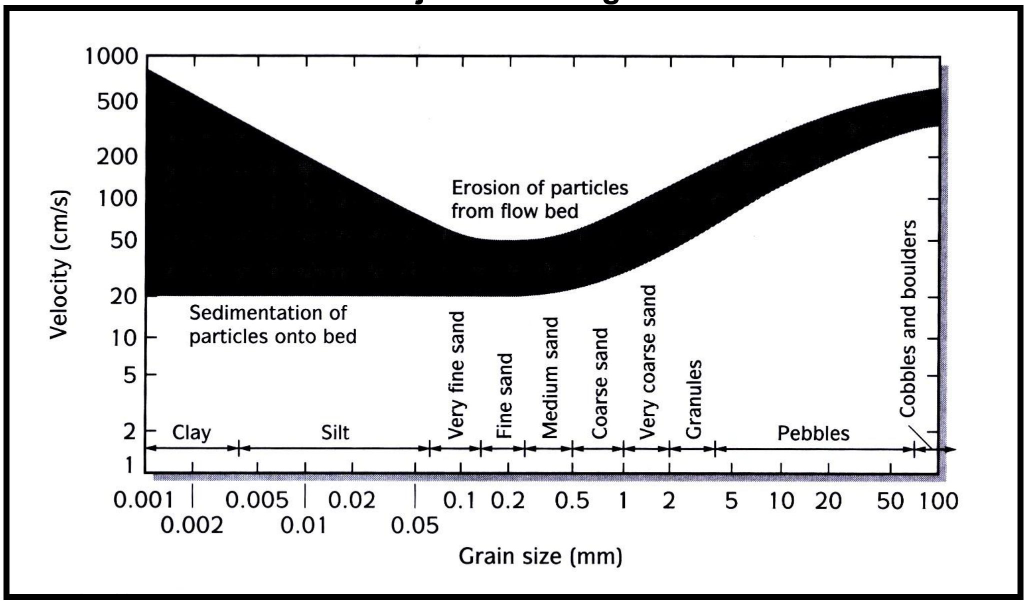


Figure 12 Taken from Prothero & Schwaub.

2. Grain size trends: Change in grain size within a bed either vertically or laterally indicates a change in flow competency. A bed can exhibit a coarsening upward trend (reverse grading) indicating an increase in flow competency or a fining upward trend (normal grading) indicative of waning flow velocities. If the bed shows a lateral variation in grain sizes than it is an indication of relative proximity to the source of sediment.

While grain size trends are not represented by a particular set of data, like grain size itself, it still represents an observable characteristic of the outcrop as a whole. Grain size trends can be seen in both the measured section and, to a certain degree, on the outcrop itself.

3. Bed thickness: The thickness of a bed is a reflection of the duration of deposition or the intensity of a depositional event. Lacustrine shales are deposited at a slow rate so a thick package of such shales implies a long period of perennial inundation. Conversely, a thick package of deltaic turbidites or debris flow deposits can be deposited relatively quickly indicating an intense depositional event.

Bed thickness is measured by either using a Jacob's Staff or a tape measure. The Jacob's Staff may be used when the total thickness of a bed cannot be reached and measured by a tape measure. The staff is 1.5m long and is divided into 10cm increments. There are no length divisions smaller than 10cm marked on the staff so any measurement that falls within one the 10cm zones is interpreted and can have a margin of error of between 1 → 9cm. The preferred method of measuring bed thicknesses is with a tape measure. The tape is divided into meters, centimeters and millimeters. Beds were measured using only the meter and centimeter divisions. This allows for greater accuracy than the Jacob's Staff measurements. Because the beds were not measured on the millimeter scale the margin of error for bed thickness is 10 mm (1cm). Measured bed thickness can vary due to measurement error, weathering effects on the outcrop or due to actual changes within the bed. These actual changes are a function of their deposition and are categorized as bed geometries.

4. Bed Geometries: The shape of a bed can be useful in determining depositional environments as well. Beds can be tabular or amalgamated, or lensoidal or sheet-like depending on their environments (Fig 13). Channel deposits are often lensoidal in cross-section while crevasse or terminal splay sands are usually sheet-like. If the base of a bed exhibits very little of no scouring of the bed beneath it than it will be tabular. If there is a degree of basal scour than such scour will cause the bed to amalgamate with a bed beneath it.

Due to limited exposure of the observed outcrops in this project only two-dimensional bed geometries can be assessed. Bed geometry is usually only observable on the outcrop and not obvious in the measured sections.

5. Stacking Patterns: The order in which beds of a certain grain size, thickness or geometry occur can give the same sort of information as do grain size trends, only on a larger scale. The stacking pattern of beds on an outcrop is a reflection of large-scale changes of the depositional environment. Changes such as rise or fall of base level due to climatic conditions, eustatic changes or tectonic changes can all be reflected in the sedimentary beds of an outcrop.

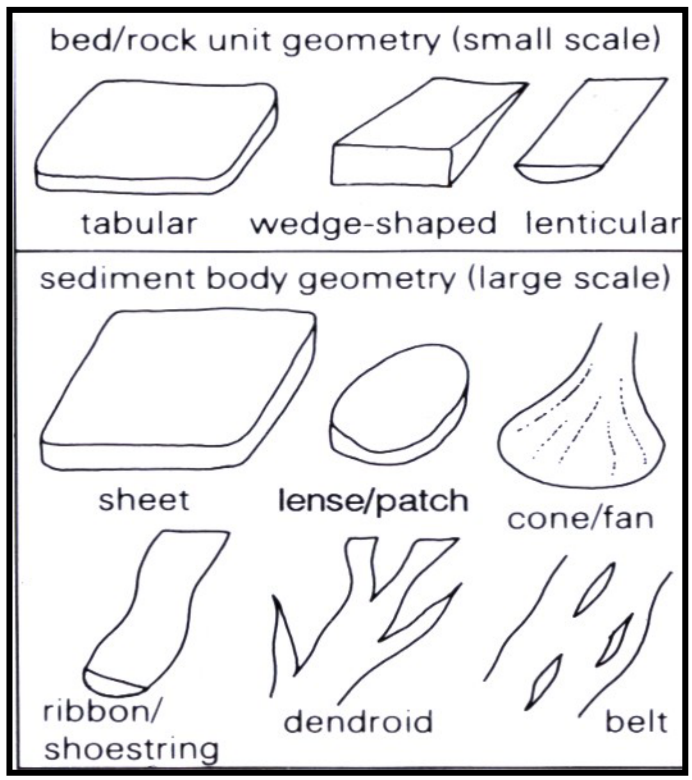


Figure 13 Bed geometries (Tucker 1996)

6. Sedimentary Structures: There are a broad range of specific sedimentary conditions, events and characteristics that are reflected in the occurrence of sedimentary structures. Due to the large number of such structures, only the ones pertaining to this specific paper will be discussed and will be done within the context of specific locations.

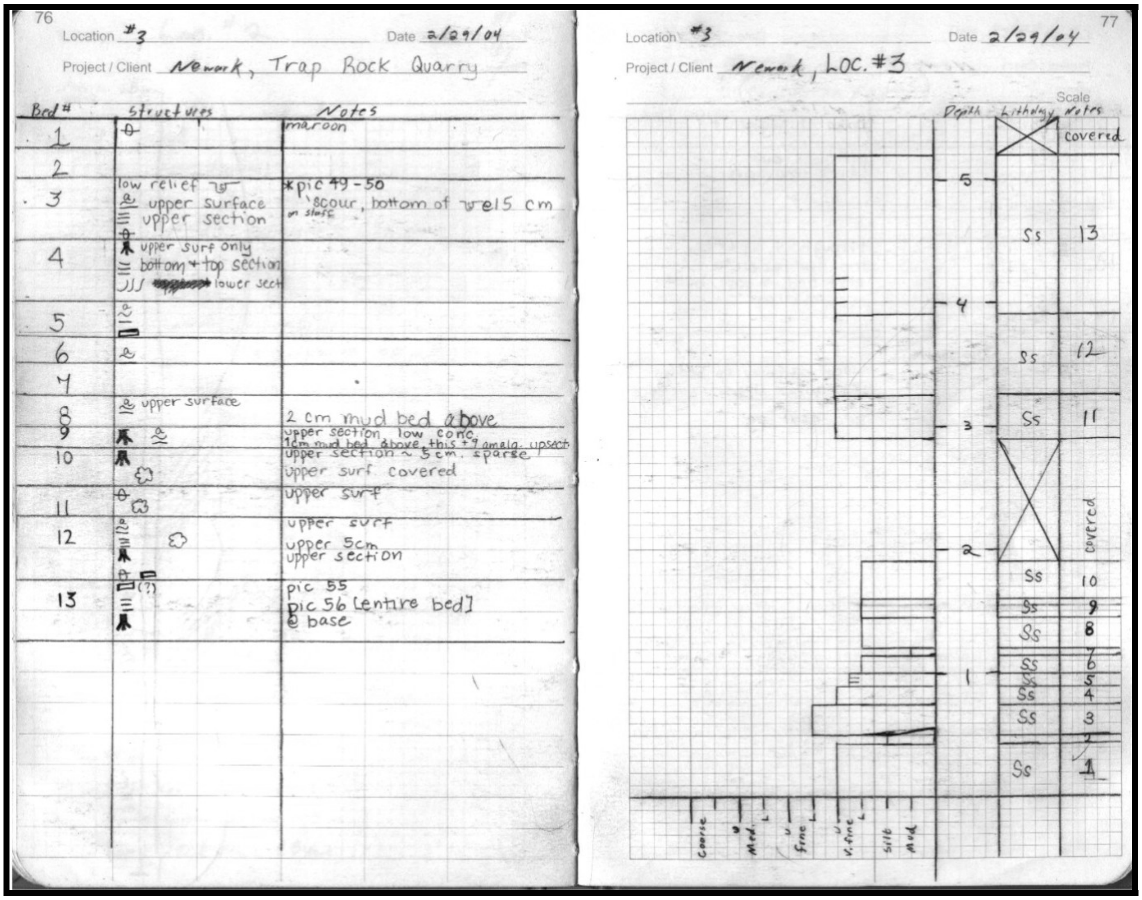


Figure 14 **Example of measured section taken from field notebook for Trap Rock Quarry location.**

4.2 Core Descriptions

The cores of the Newark Basin Coring project have been used in this project for the purpose of correlating the change in depositional characteristics from one part of the basin to another. The NBCP removed nine cores from seven locations throughout the Newark Basin. They were taken from Princeton, Somerset, Nursery, Titusville, Weston, Rutgers and Martinsville. Olsen et al. (1997) compiled all of the data from the core records and developed a basin-wide correlation based upon the most recognizable and continuous aspects of certain members within each formation. From this information, the outcrops that were used for this project have been correlated to the core record. After the correlation was established the same data that were gathered in the field were also gathered from the Somerset core #1. A core log, in similar format to the measured sections, was then compiled. Somerset New Jersey, the location from which the core was taken, is located ~65 miles from the project field area in Pennsylvania.

4.3 Field Locations

Three of the five field locations for this project were taken from "Field Trip Guidebook T351" (Olsen and Gore, 1989) that was published by the American Geophysical Union. The locations are denoted as follows: (1) Railroad Cut, (2) Roadside Quarry, (3) Trap Rock Quarry, (4) Pebbles Bluff, (5) Nockamixon Cliffs. Locations 1,2 and 4 are described in the field guidebook. Location 2 has been established as belonging to the Metlars Member of the Passaic Formation (Olsen and Gore, 1989). Using this correlation, and based upon the proximity of location 1, location 1 most likely belongs to the upper most Livingston Member and lowest Metlars. From these correlations we were able to place ourselves within the extensive core record. Location 4 belongs to the LM Member of the middle Passaic. Its location relative to that of location 4 places the Nockamixon Cliffs exposure probably within the Perkasie Member of the Passaic.

The Railroad cut, Roadside quarry, Traprock Quarry and Pebbles Bluff locations are all represented by measured sections and photopans. The Nockamixon Cliffs location is represented by photographs only due to problems acquiring a measured section which will be discussed in the presentation of data section for that location.

The portion of the Passaic that is represented by measured sections in this paper lies within the middle → upper portions (fig. 3). Relative lake levels within the basin can also be estimated from the stratigraphic column. The Metlars and Livingston members (locations 1 & 2) were deposited in a time when deep, perennial lakes episodically filled the basin. The rocks from location 1 and 2 were deposited during the third Triassic Epoch within the Norian Sub Epoch (209.5 – 223 mya) which had the wettest climate out of all the members observed in this project. Shallower lakes were typical of the Perkasie and LM members which were observed at Pebbles Bluff and Nockamixon Cliffs. These were also deposited during Norian times, only slightly earlier. The stratigraphic location of The Traprock Quarry location is unknown but its approximate location is with the upper most Passaic, when basin lake levels were very low.

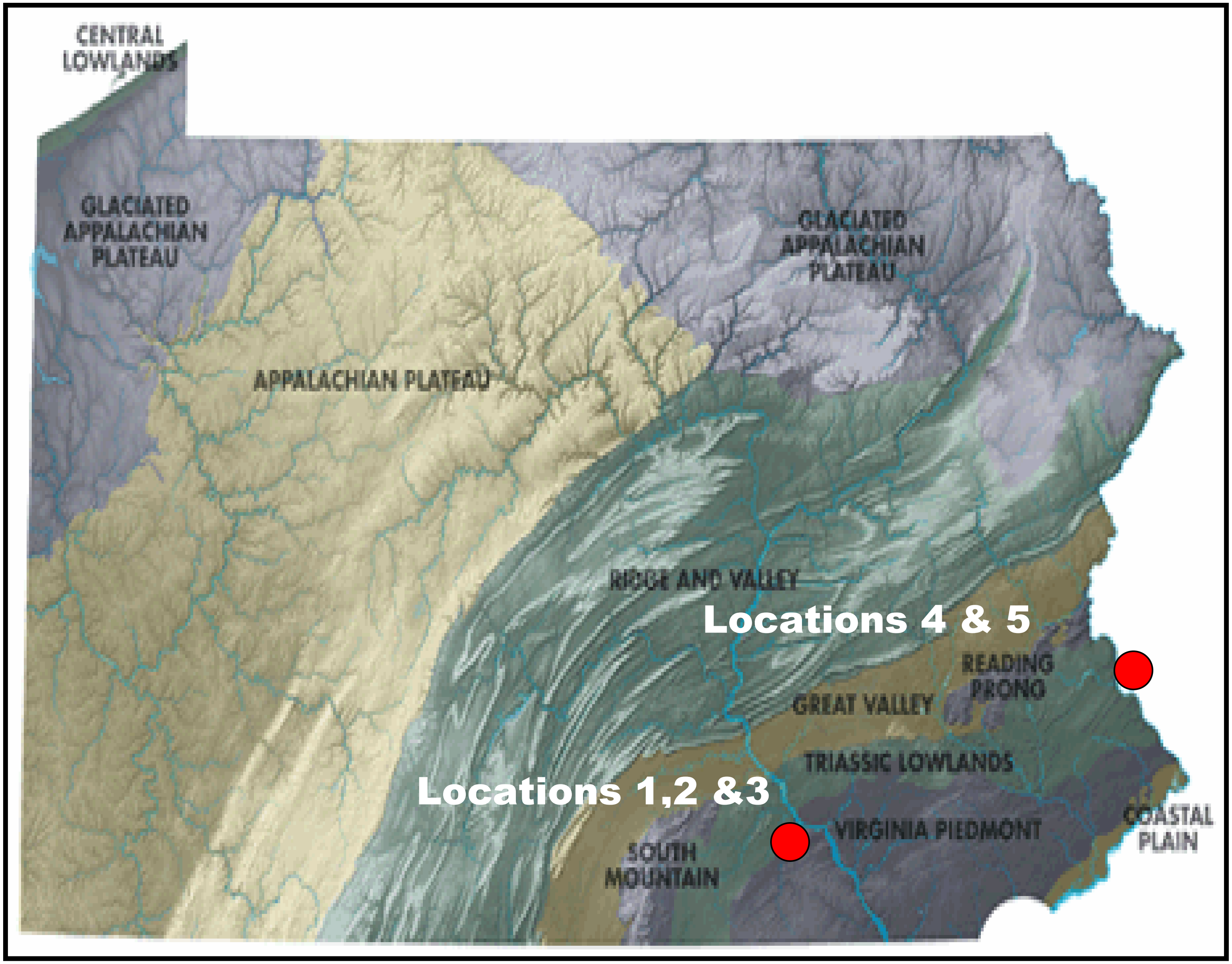


Figure 15 Topographic map of Pennsylvania showing field locations ● Taken from map database of the University of Texas web site

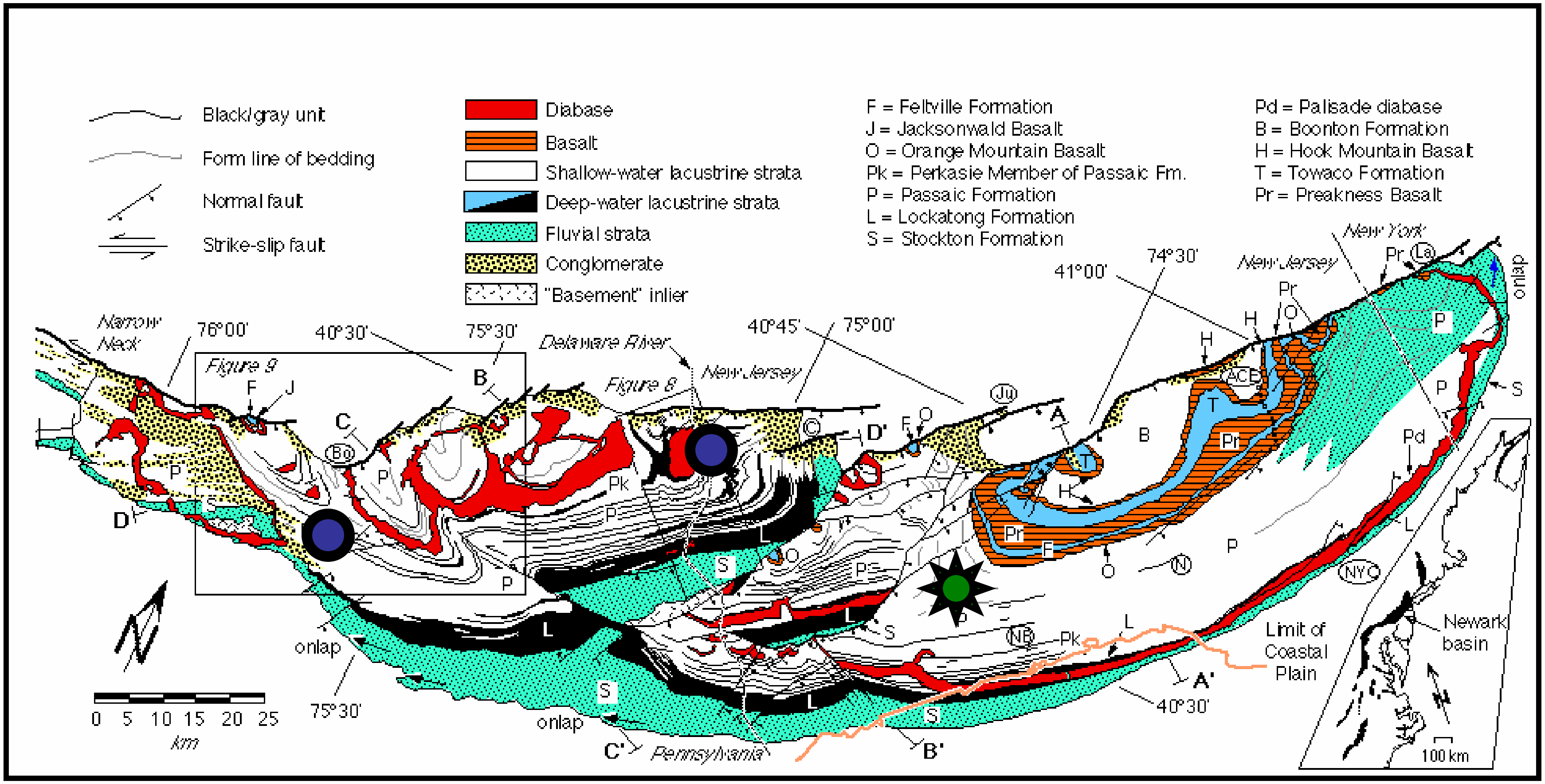
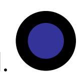
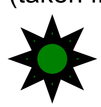


Figure 16 Newark Basin Geological Map (taken from Olsen, 1997) with field locations marked. 

Location from which Somerset core was taken 

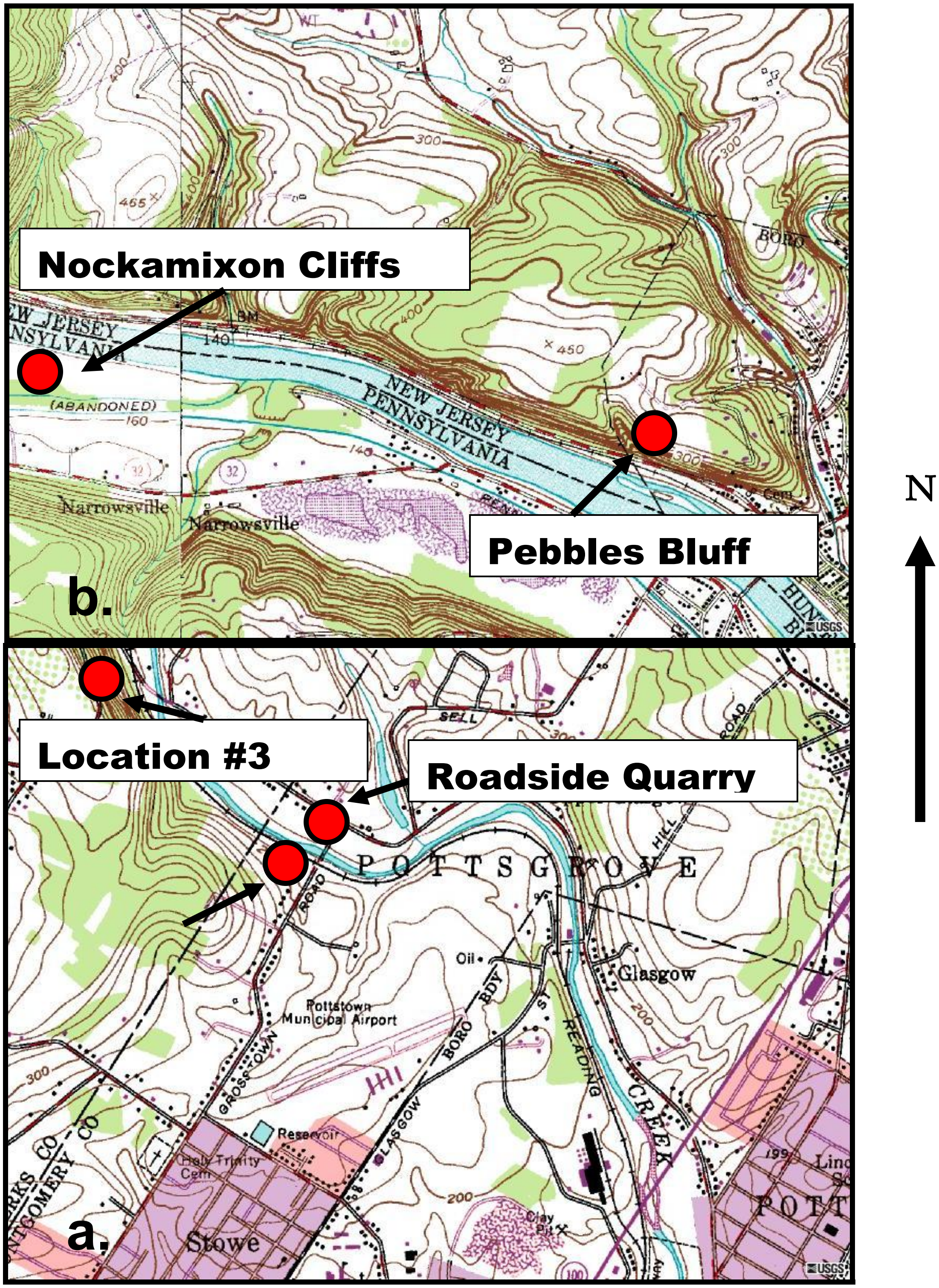


Figure 17 Maps showing all field locations. www.mapquest.com

5. Data

The primary data sets are the measured sections that have been compiled in the field. The following abbreviations will be used in the presentation of data tables that accompany the graphic logs.

Sedimentary Structures:

Planar Laminations (PL)	Planar Crossbeds (PC)	Bioturbation (Bt)
Surface Ripples (SR)	Climbing Ripples (CR)	Massive Bedding (M)
Mudchips (MC)	Mottled structure (Mt)	Sheared Bedding (SB)
Vertical Burrows (VB)	Wavy Laminations (WL)	Trough Crossbeds (TC)
Desiccation Cracks (DC)	Scour (Sc)	Carbonate Nodules (CN)
Soft Sediment Deformation (SS)		Pencil Cleavage (PC)
Horizontal Burrows (HB)	Root Casts (RC)	Mud Drape (MD)

Grain Size:

Clay (c) Silt (slt) Very fine lower (vfl) Very Fine Upper (vfu)

Fine Lower (fl)

Fine Upper (fu) Medium Lower (ml) Medium Upper (mu)

Coarse Lower (cl) Coarse Upper (cu) Very Coarse Lower (vcl)

Very Coarse Upper (vcu)

Lithology:

Mudstone (Ms) Siltstone (St) Sandstone (Ss)

Figure 18 Abbreviations that will be used in the data tables for the description of each field location.

5.1 Railroad Cut (Loaction 1)

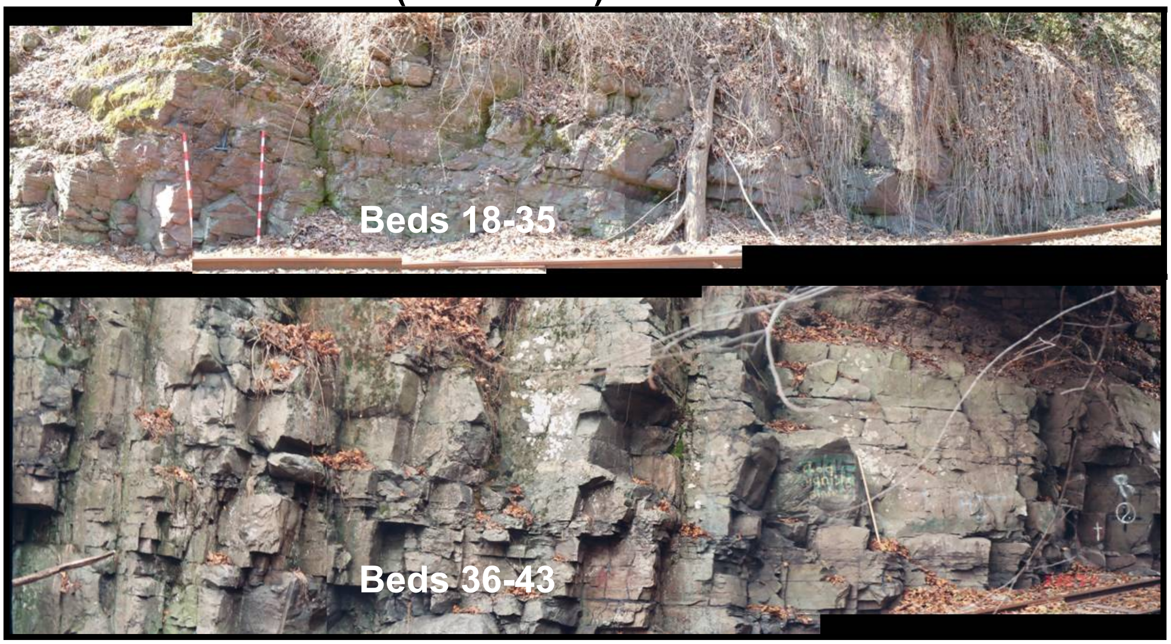


Figure 19 Upper half of the outcrop at location #1.

The railroad cut through the upper Livingston and lower Metlars Members of the Passaic Formation occurs along Matatawny Creek just outside of Pottstown Pennsylvania. The outcrop is divided into two main sections that are separated by an extensive covered interval. Grain size trends vary from mud to fine sand. Grain size trends vary as well; the upper section is relatively coarser than the lower. Most sandbeds are either capped by muds or divided by thin muddy interbeds. The degree of bed amalgamation increases upsection, however, beds are mostly tabular and generally continuous with sharp basal contacts. The general trend is that of muddier sandstone units below to sandier beds above. Bed thickness varies from 5 cm to 2m. Bed color varies from light red at the bottom, grey in the middle beds and the entire section is capped by another succession of weathered red beds

The beds at this location dip at a 5-10° angle to the E →SE. The total thickness of the section is just under 23 meters. The outcrop extends laterally for ~143 meters and vertically from ~1 meter to 7 meters. The lower section of this outcrop is dominated by thick, massive red beds which give way to thinner red beds and then to very tabular, sharp based buff-colored sandstone beds that are separated by either thin (~1-4 cm) mud beds or are draped in mud (beds 18 – 42, Figure 21 e.). Throughout these upper beds can be found root casts, climbing ripples, planar bedding, surface ripples, carbonate nodules and mud drapes (Figure 21).The outcrop is capped by a bundle of highly weathered, thinner red beds

Bed #	Thickness (cm)	Lithology	Color	Grain Size	Sedimentary Structures
1	120	St	red	slt	WL, PL, PC
2	30	Ss	red	vfu.	Sc, WL
3	180	Ss	red	vfl	M
4	40	Ss	red	vfl	PC, M
5	35	Ss	red	vfu	SC
6	57	Ss	red	vfu	
7	46	Ss	red	vfu	
8	50	Ss	red	Vfu	
9	190	Ss	red	vfl	PC, M
10	70	Ss	red	vfu	SR
11	65	Ss	red	vfu	
12	120	Ss	red	vfu	
13	100	Ss	red	vfl	Zone of muddy laminations towards bottom.
14	30	Ss	red/ gray	fl	PL,
15	120	Ss	gray	vfl	PL
16	112	Ss	gray	vfl	PL
17	62	Ss	gray	vfu	PL
18	40	Ss	gray	vfl	CN, Sc
19	20	Ss	gray	vfl	MC, CN, Sc
20	60	Ss	gray	vfu	CN, RC, SR
21	82	Ss	gray	vfu	CN, SR
22	18	Ss	gray	vfl	PL,
23	31	Ss	gray	vfl	SR PL
24	130	Ss	gray	vfl	SR
25	28	Ss	gray	fl	SR
26	60	Ss	gray	fl	M
27	30	Ss	gray	vfu	SR
28	15	Ss	gray	vfu	SB Sc WL
29	8	St	gray	slt	SR
30	40	Ss	Gray/ Green	vfu	SR WL
31	13	Ss	gray	vfu	SR WL
32	34	Ss	gray	vfu	
33	42	Ss	gray	vfu	
34	65	Ss	gray	vfu	
35	185	Ms	Black	c	laminated
36	130	Ss	lt Gray	fl	Dc TC WL
37	8	Ss	lt Gray	vfl	SR WL
38	65	Ss	lt Gray	fl	PL WL PC SR
39	9	Ss	lt Gray	slt	SR Sc Pinches out downdip
40	32	Ss	lt Gray	fl	SR
41	20 - 30	Ss	lt Gray	fl	CR SR pinches out downdip
42	250	Ss	lt Gray	fl	PL
43	30	Ss	red	fl	PL WL SR
44	25	Ss	red	fl	PL WL SR

Table # 1 Data from measured section of location #1

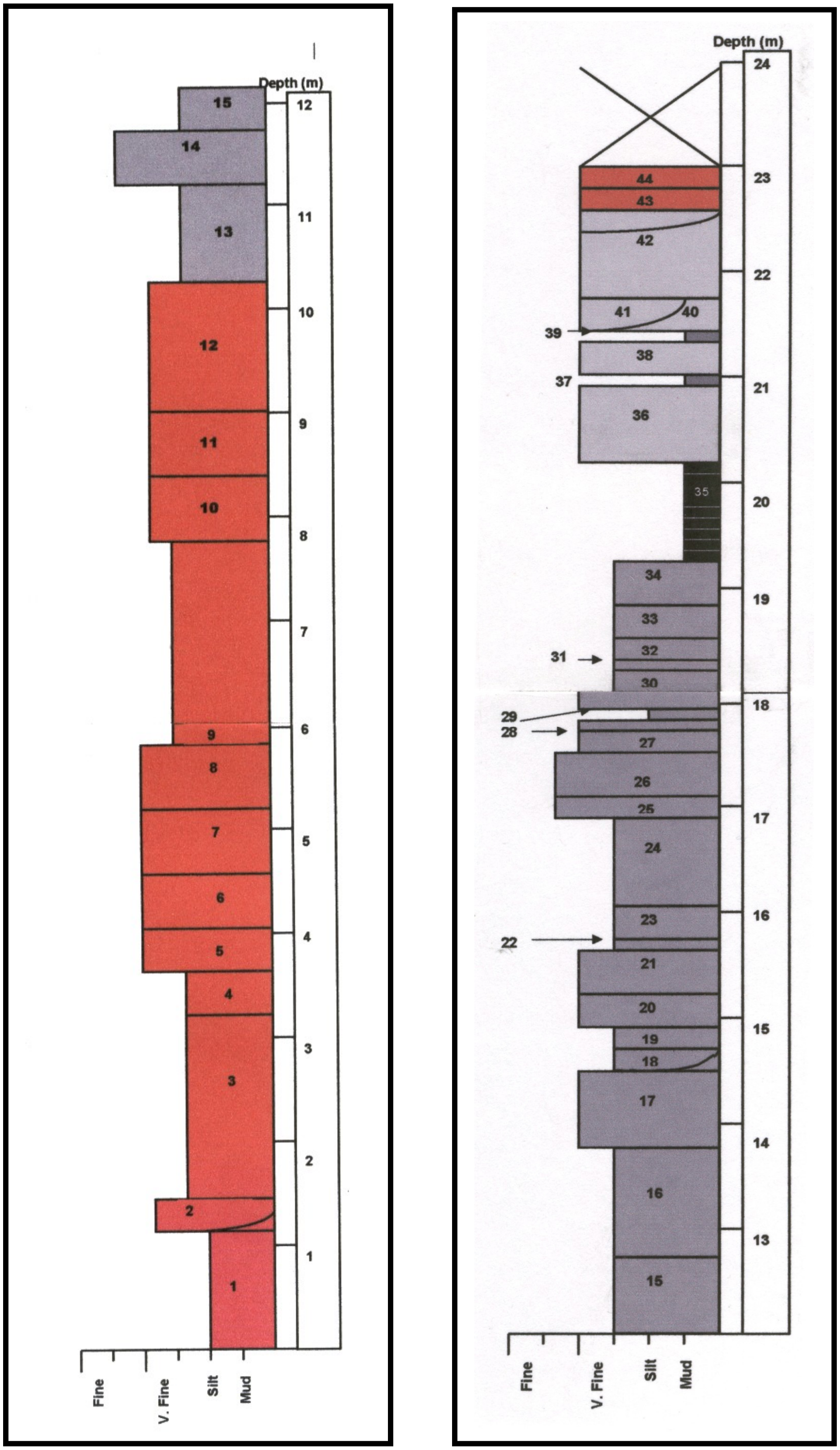


Figure 20 Measured section for location #1 showing 8 cycles of coarsening upwards trends.

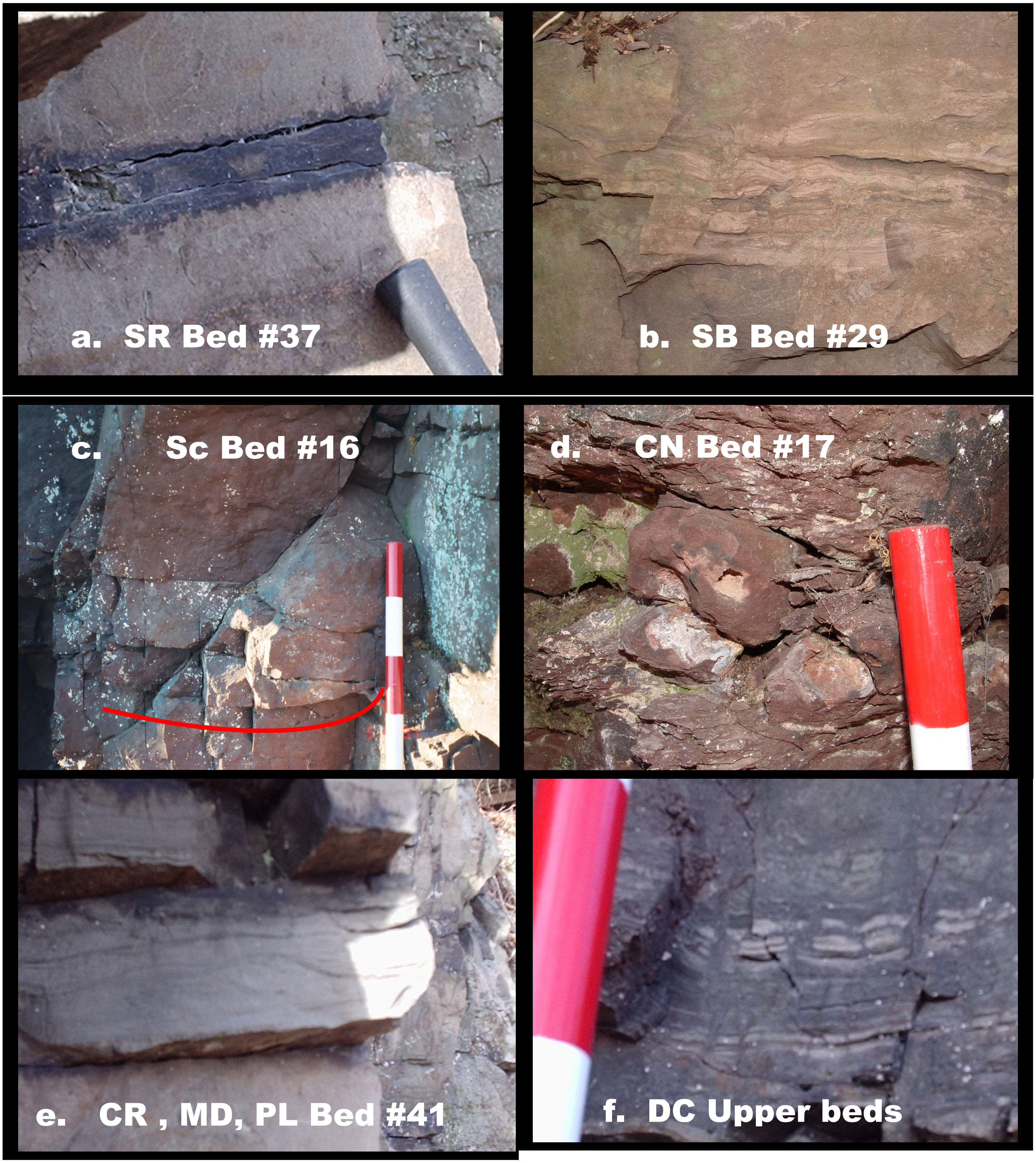


Figure 21. Important structures found at location 1

Figure 22. Upper part of location 1 showing tabular sandbeds separated by thin muddy/silty beds. Circle marks location of picture shown in Fig. 21 e.

5.2 Roadside Quarry (2): Pottstown, PA

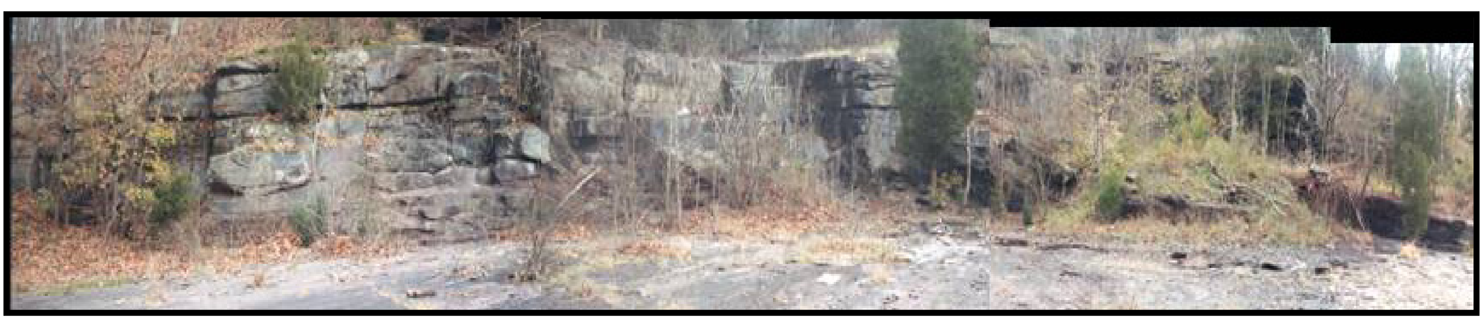


Figure 23. Photopan showing location 2.

Field location #2 is an outcrop within a small abandoned roadside quarry. It is located along Manatawny St. outside of Pottstown, PA .3 miles from the railroad cut location. The road along which the quarry lies is topographically equivalent to the top of the cut bank of Manatawny Creek below which sits the entire portion of the railroad cut section. This position indicates that the lowest red beds of this location most likely coincide with the uppermost red beds of location #1. The rocks that are exposed here belong to the Metlars Member of the Passaic Formation (Gore & Olsen, 1989).

The quarry was cut in a horseshoe shape whose width at its widest point is ~60-80 meters across. There is good, continuous vertical exposure of just under 6 meters and poor, discontinuous exposure of approximately another 4 – 5 meters. The rocks above the section that was measured, where they crop out, are black and gray fissile shales that have been interpreted as having been deposited in deep, perennial lakes (Gore & Olsen, 1989). The quarry floor is an intensely mud cracked surface and is covered in desiccation polygons. The basal red beds of the outcrop are thin, very fine grained sand beds that are capped by red mud drapes which are cracked. There are between 2-4 such beds that are on the scale of ~3-7 centimeters that lie beneath the lowest bed of the measured section. These beds are exposed randomly along the quarry floor and, due to cover, could not be accurately correlated to the larger exposed rocks which make up the measured section for this location. The beds that make up the section can be followed laterally for 15 – 20 meters around the quarry. The beds can be divided into two generally thickening upwards cycles capped by a +/- 1 meter bed of thick black shales. The outcrop as a whole is similar in character to that of location #1. The beds are tabular, very fine – fine grained sandstones. The basal contacts of the sandstone beds at this location do not appear to be as sharp as those at the railroad cut and do exhibit some amalgamation, most notably in the area of beds 4,5 & 7.

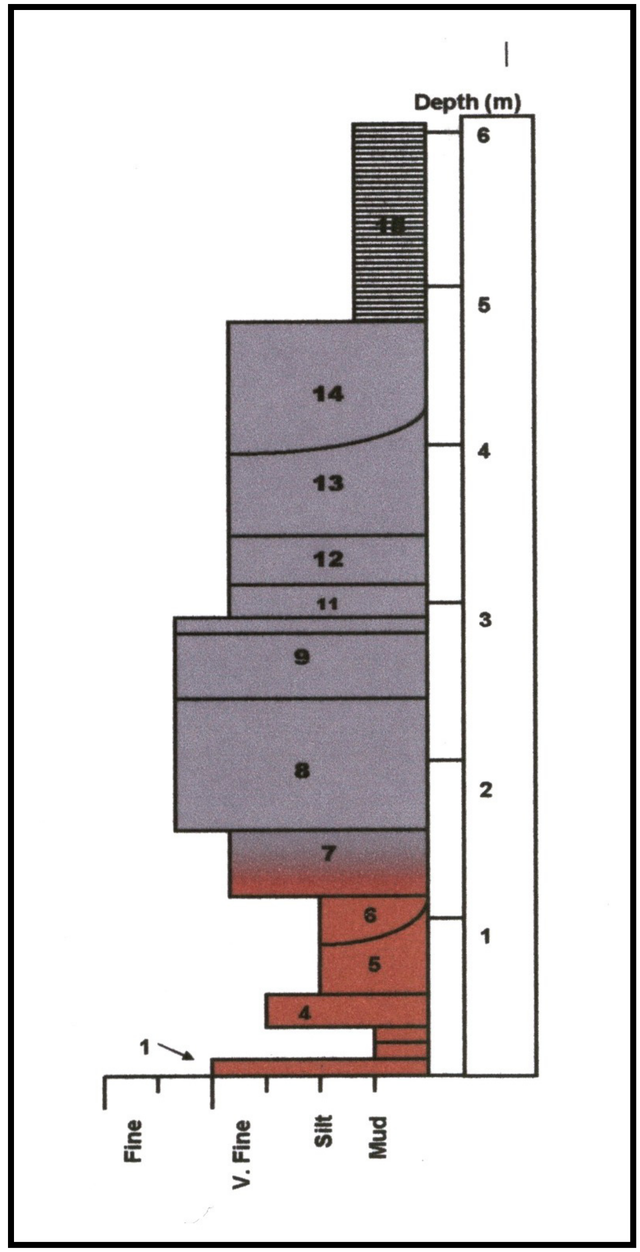


Figure 24 Measured section from location 2

Bed #	Thickness (cm)	Lithology	Color	Grain Size	Sedimentary Structures
1	7	Ss	Red	Vfu	DC PC
2	14	Ms	Red	C	DC SR
3	27	Ms	Red	C	DC SR
4	23	Ss	Red	Vfl	PC
5	46	St	Red	Slt	M
6	20	Ss	Red/gray	Vfl	
7	40	Ss	gray	Vfu	
8	78	Ss	gray	Fl	
9	45	Ss	gray	Fl	Sc SR
10	4	Ss	gray	Fl	
11	28	Ss	gray	Vfu	RC SR VB
12	35	Ss	gray	Vfu	PL PC RC
13	140	Ss	gray	Vfl	M RC
14	15	Ms	black	c	laminated

Table 2 Data from location 2

Key Structures

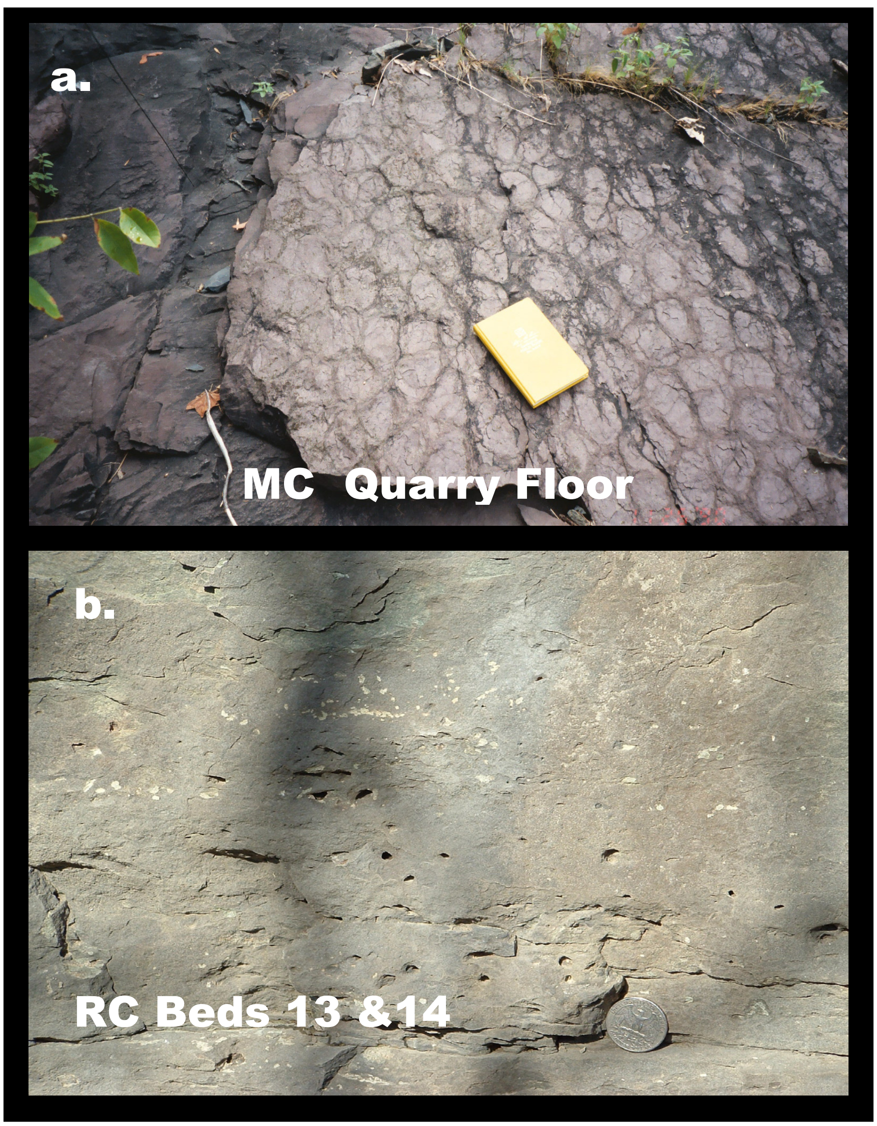


Figure 25.

5.3 Trap Rock Quarry

Figure 26 North (lower) and East (upper) faces of quarry at location 3.

The third field location is located 1.5 miles northeast of the previous two locations. It is an abandoned quarry in Berks County Pennsylvania that is now a private residence. Its exact stratigraphic position is not known, however, judging from its relative position, dip angle and dip direction, it is most likely one of the uppermost members of the Passaic Formation. This outcrop has excellent vertical and lateral exposure; however, the shear quarry walls only allow for safe access to the lower 15 meters in one particular spot along the quarrie's north wall. Beds can be tracked laterally for ~30 meters. Vertically, the quarry exposes nearly another 30 → 40 meters.

The Passaic at this location has characteristic differences from its exposure at the previous two locations. The upper Passaic was deposited in relatively drier times (Fig. 3) which is reflected in the lack of any significant shale deposits at this location. There are far less mud and silt size deposits than were found at locations 1 &2 as well as the fine muddy interbeds that are common in the first two locations. Most of the beds at this location fall into the upper very fine or lower fine categories (Table 3), in contrast, the first two locations contained fine grained beds but were dominated by lower very fine and silty beds. There are numerous similarities between the three locations as well. First, the sandbeds are very tabular in nature. Some basal scour is exhibited in beds 3 & 15 (see below table and Fig. 29a) but it is very low relief in nature. There is an abundance of Calcerous nodules similar to the railroad cut found in beds10, 11, 12, 14 & 19. They also occur in high concentration with bioturbated surfaces in float scattered along the quarry floor (fig. 29 b & c). Rooted horizons, similar to locations 1 & 2 occur as well.

Bed #	Thickness (cm)	Lithology	Color	Grain Size	Sedimentary Structures
1	41	Ss	D. red	vfu	HB
2	12	Ss	Gray	slt	
3	25	Ss	Gray	fl	SR, Sc, PL, HB
4	15	Ss	Gray	vfu	RC PL TC
5	10	Ss	Gray	vfl	SR MC
6	15	Ss	Gray	Vfl	SR
7	10	Ss	Black	C	
8	23	Ss	Gray	vfl	SR
9	12	Ss	Gray	Vfl	RC SR
10	30	Ss	Gray	Vfl	RC CN
11	35	Ss	Gray	vfu	HB CN
12	65	Ss	Gray	vfu	SR RC PL HB CN MC
13	130	Ss	Gray	vfu	MC PL RC
14	110	Ss	Gray	vfu	RC CN
15	17	Ss	D. red	vfu	Sr
16	110	Ss	Gray	vfu	SR
17	20	St	Gray	Slt	
18	90	Ss	Gray	vfu	RC
19	100	Ss	Gray	vfu	RC
20	13	St	Gray	vfl	RC
21	50	Ss	Gray	fl	RC
22	160	Ss	Gray/green	vfu	PL
23	24	Ss	Gray	vfl	PL
24	90	Ss	Gray	vfu	CN M
25	70	Ss	Gray	vfu	CN M
26	30	Ss	Gray	vfu	CN M
27	10	Ss	Gray	SR	Vfl
28	50	Ss	Gray	Vfu	
29	30	Ss	Gray	vfu	

Table 3. Location 3

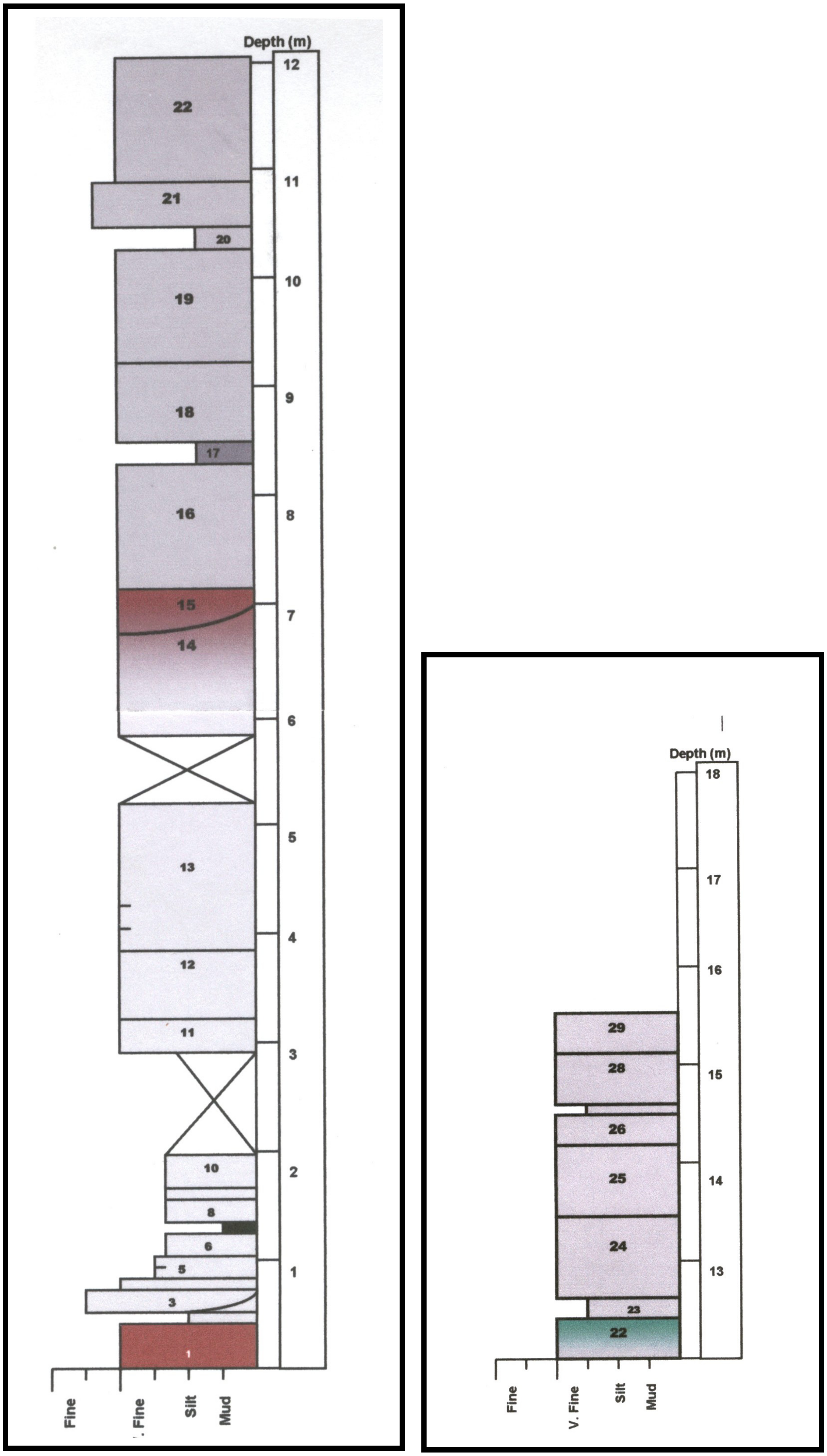


Figure 28 Measured sections for location 3.

Key Structures

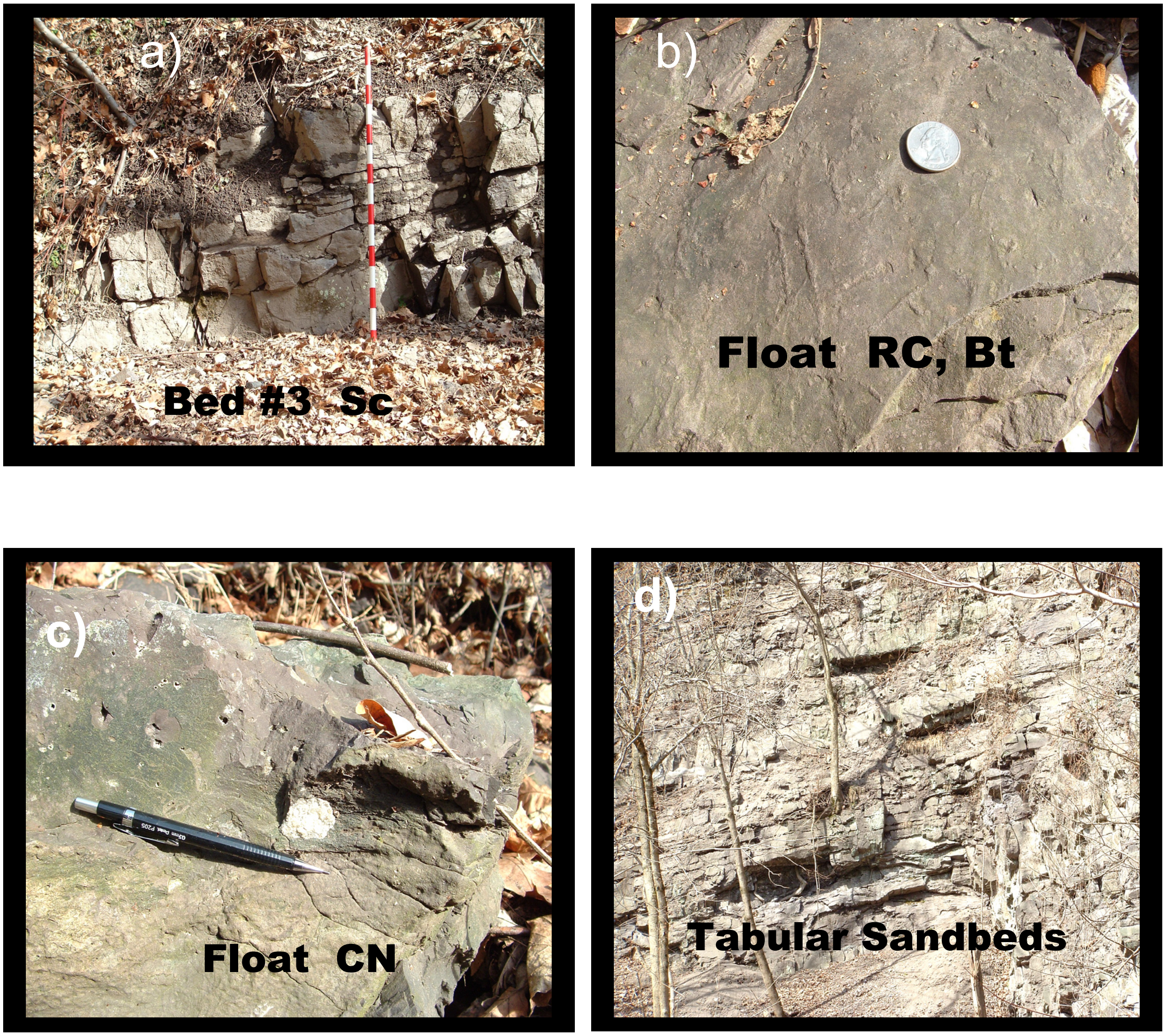


Figure 29 Important structures found at location 3

5.4 Pebbles Bluff

Figure 30 Entire vertical exposure of measured section at location 4.

Pebbles bluff is located along the Delaware River in Hunterdon County, New Jersey. There is excellent exposure of the LM Member of the Passaic (as correlated by Gore & Olsen, 1989) ~ ¾ mile upstream of where the measured section was taken. The upper exposure has been interpreted as having been deposited in very coarse grained braided streams and alluvial fans. The outcrop where the data for this project were taken lies to south of the upper section, just outside of the town of Milford. This location sits nearly in the center of the Newark Basin in a much more proximal position to the main bounding fault system (Fig. 16) which accounts for the coarse grained nature of the upper section.

Location 4 has good lateral exposure that is limited only by the dip of the beds (Fig.39). The vertical exposure is ~ 18 meters but only the 13 meters that were measured are safely accessible. This outcrop is nearly completely different from the rest of the outcrops that have been used for this project. The idea behind the use of this location is to see how fluvial components change as a function of their position within the basin. The coarse grained facies change dramatically. The average grain size for this location is between lower fine and upper medium. There are intervals of mud, but they are red and non-fissile compared to the black/gray, fissile shales and mudstones from previous locations. The muddy beds here resemble the lowest beds of location 2. They are thin (1- 5 cm) red beds that each show evidence of exposure in the from of mudcracks (Fig. #, Bed 16). This outcrop can be divided into three sections. The basal section varies from lower fine grained to lower medium grained. The beds are relatively structureless with surface ripples present on the surfaces of some beds (refer to table below). From a distance, large scale low angle cross-beds can be seen (lateral accretion surfaces). The middle is made up of bed 16 which is >1 meter of thinly bedded red mudstone. The upper section is coarser grained than the lower. Bed 17 has a scour base with graded clast channel fill and is mostly massive. The rest of the section consists of two fining-upwards series of beds and within each can be found a series of cyclical structures from bottom to top which is → massive bedding →planar laminations → current ripples. Above this lies another section of thinly bedded mudstones, however, this section is inaccessible.

Bed #	**Thickness (cm)**	**Lithology**	**Color**	**Grain Size**	**Sedimentary Structures**
1	60	Ss	red	fl	M
2	30	Ss	red	Fl	M
3	60	Ss	red	Fl	M
4	65	Ss	red	Fu	SR
5	10	Ss	red	fu	SR
6	5	Ms	red	c	
7	10	Ss	red	fu	SR
8	5	Ms	red	c	
9	10	Ss	red	fu	Sc
10	60	Ss	red	ml	
11	25	Ss	red	fu	
12	12	Ss	red	vfu	
13	25	Ss	red	vfu	
14	35	Ss	red	fl	M
15	80	Ss	red	vfu	
16	160	Ms	red	c	DC
17	160	Ss	red	ml	TC PL RC SR DC Sc HB VB
18	30	Ss	red	fu	PL TC
19	90	Ss	red	vfu	M PL SR
20	45	Ss	red	Vfu	M PL SR
21	30	Ss	red	vfu	M PL SR
22	20	Ss	red	vfl	M DC
23	10	Ss	red	fu	PL SR
24	15	Ss	red	fl	SB
25	5	Ss	red	fu	
26	40	Ss	red	fu	M PL SR
27	10	Ss	red	vfu	SR
28	10	Ss	red	vfu	PL SR
29	10	Ss	red	vfu	MC PL SR

30	10	Ss	red	vfu	SR MC
31	110	Ss	red	c	

Table 4

Figure31. LM member of the Passaic exposed in the upper section of Pebbles Bluff. Picture taken facing North.

Figure32. Braided channel in upper Pebbles Bluff

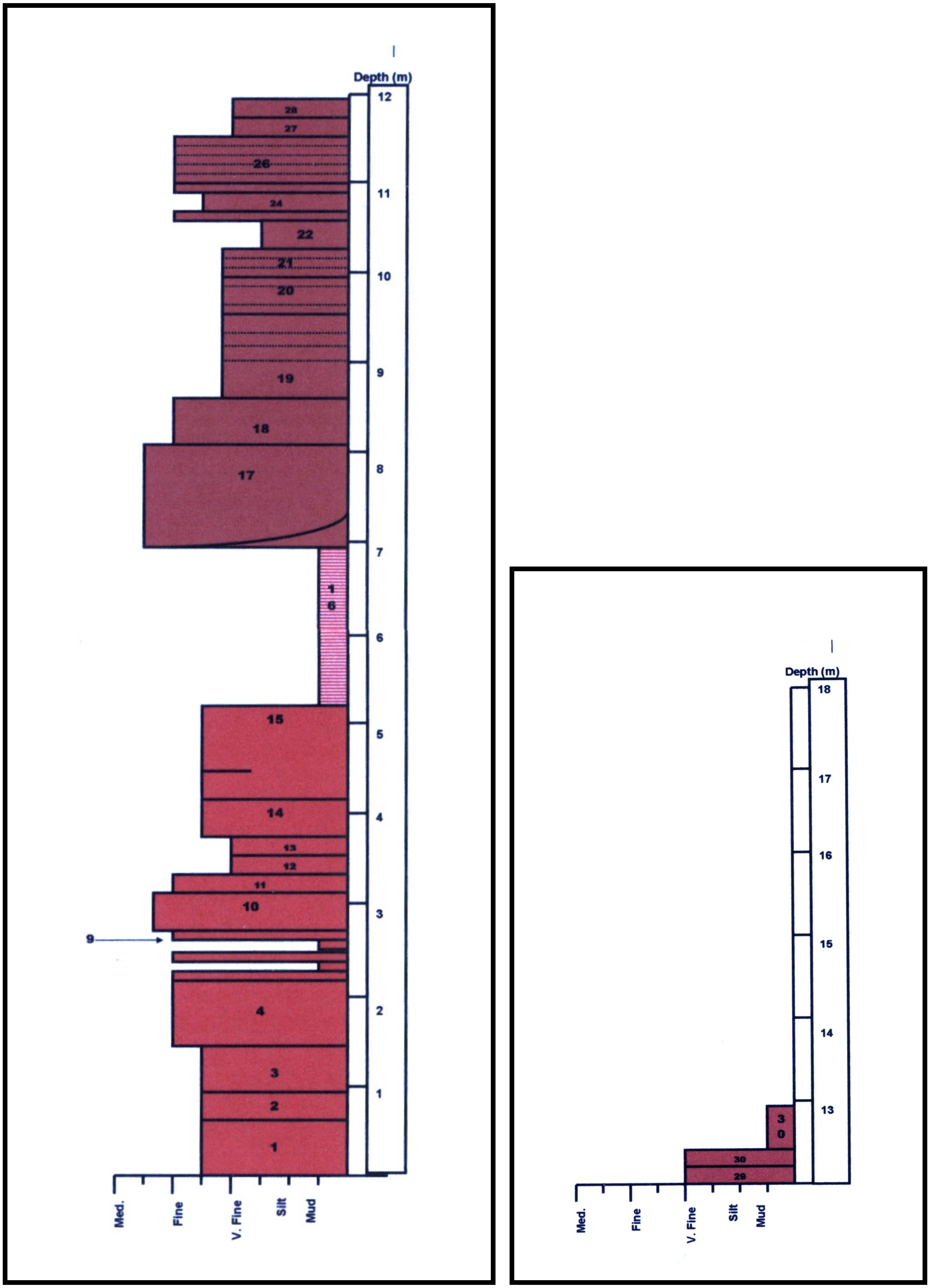


Figure33 Measured section from location 4, lower Pebbles Bluff.

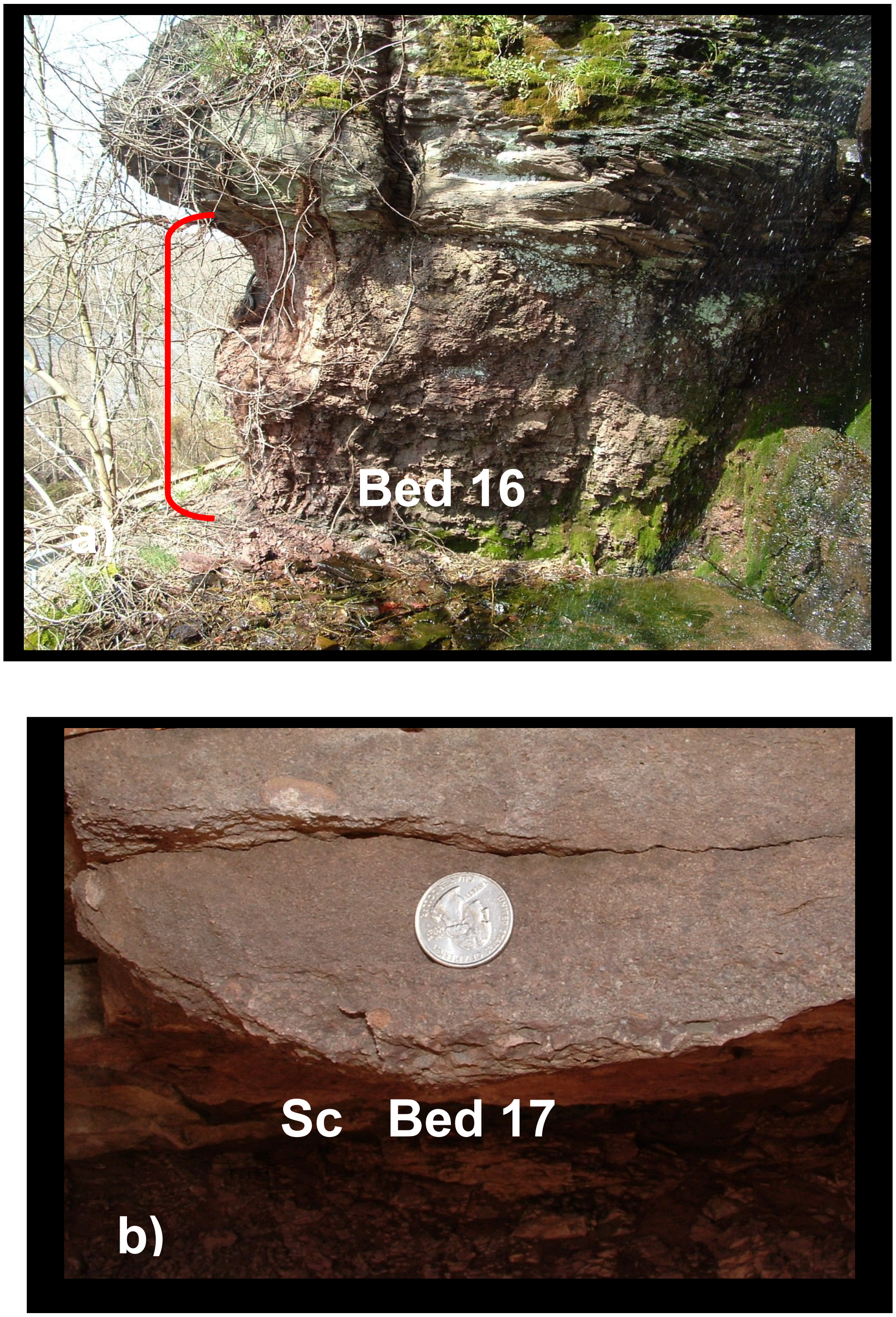


Figure34

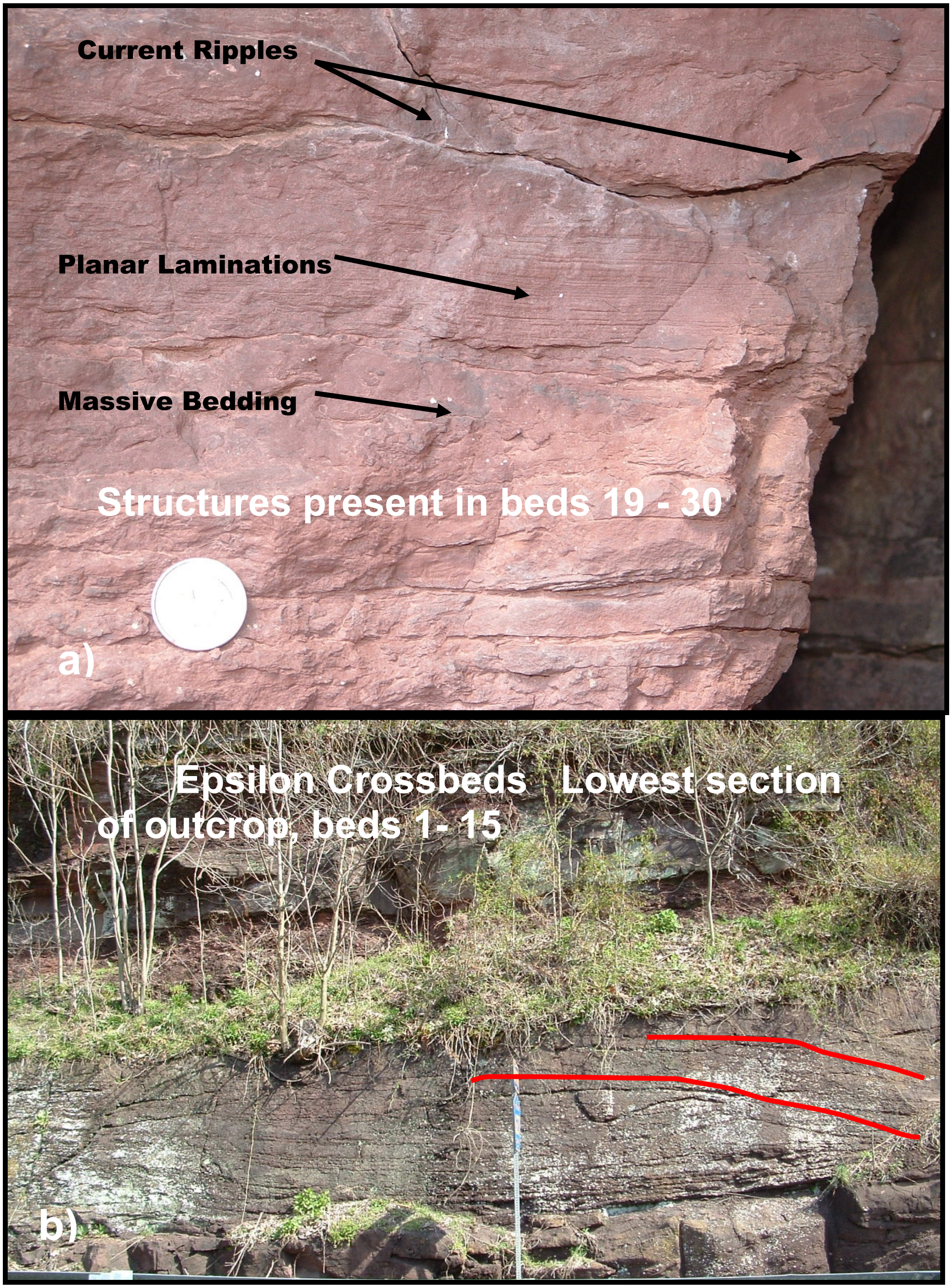


Figure35 Bed #19 (a) beds 1-15 (b)

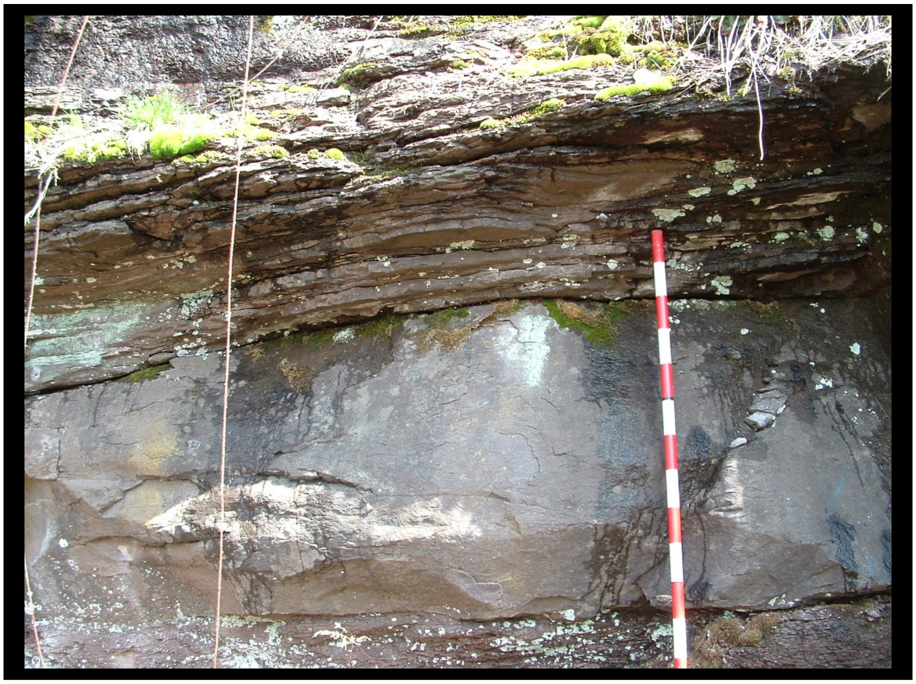


Fig 36 Contact between beds 16 and 17

Fig 37 Root casts in float from a bed ~1.5 meters above uppermost bed in Pebbles Bluff section

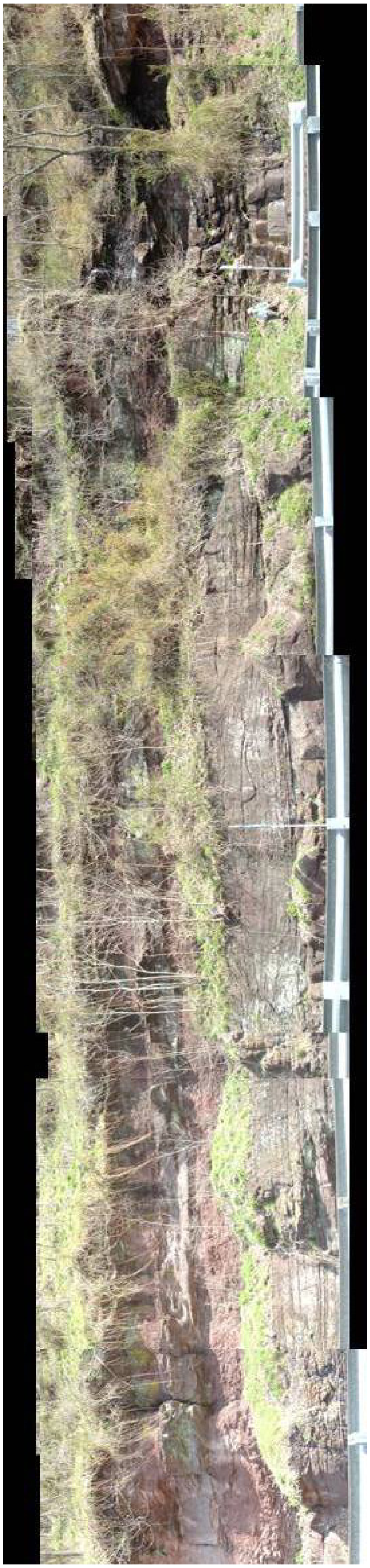


Figure 39 Pebbles Bluff exposure of LM Member of the Passaic Formation

Figure38 Sheared bedding bed 24.

5.5 Nockamixon Cliffs

The river cut that is exposed at Nockamixon Cliffs exposes 64 meters of Perkasie Member of the Passaic (as corroberated by Olsen and Schlische) . It is located south of Easton, PA and north of the Pebbles Bluff location. From the beginning of this project it was intended that there be a photopan and measured section collected from this location, however, numerous complications have prevented this from happening. First, the face is shear and without any slope by which to access beds any higher than head high. Second, the cliffs face directly north and receive very little sunlight. The base of the cliff is obscured by trees throughout the summer and fall, therefore, I intended to return in the winter to take better pictures. When I came back the entire face was obscured by ice falls (which this location is apparently famous for!). I returned one more time during the winter to find that nothing had changed, so I decided to wait until spring. The most recent trip to Nockamixon Cliffs proved to be no more useful than the first three. The ice had been replaced by moss and lichens and the trees had begun to bloom again. The proximity of the cliff to the river prevented any good, large-scale photographs from being taken and the other side of the river belongs to a concrete plant that has never been open while I was around nor was there a number or sign posting contact information.

In spite of the setbacks, some general information can be given about this location and the photographs that I do have can be presented. The outcrop is dominated by red mud and silt, much of which is massive bedded. Some structures were found in float at the base of the cliff and , though they cannot be accurately placed within the context of the exposure, they can give some information. Thinly bedded siltstones with mud draped and mudcracked surfaces resembling those of locations 2 and 4 exist. Float blocks also contain partially developed soil horizons, carbonate nodules, and root casts.

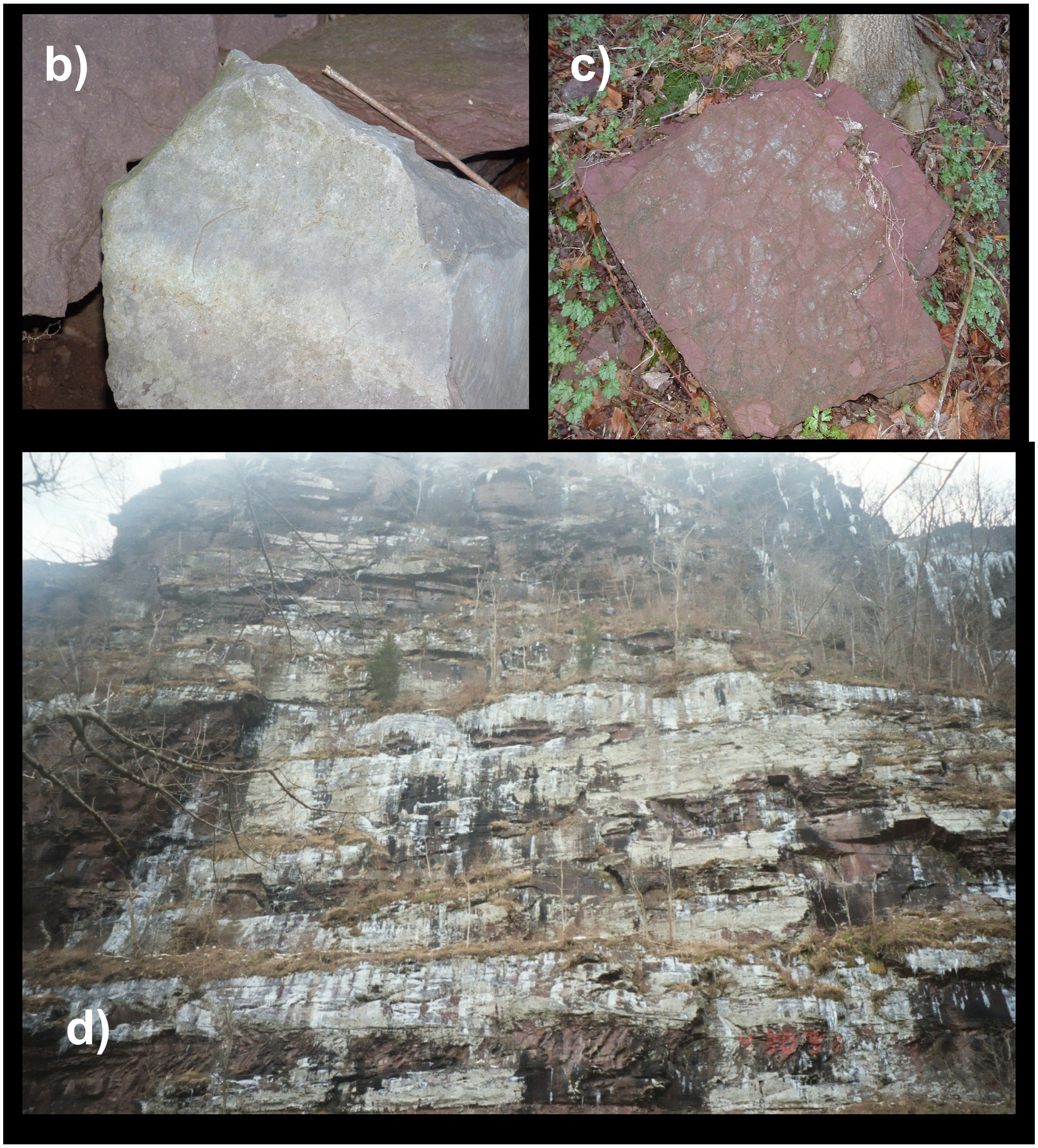


Fig.40 Nockamixon Cliffs covered in ice (a & d) . Partially developed soil horizon with root casts in the upper part (b). Thinly bedded, very fine grained sandstone with dessicatoin polygons (c).

5.5 Core Descriptions

Boxes 45 – 46

Box 47

Boxes 48 – 49

Boxes 50 -51

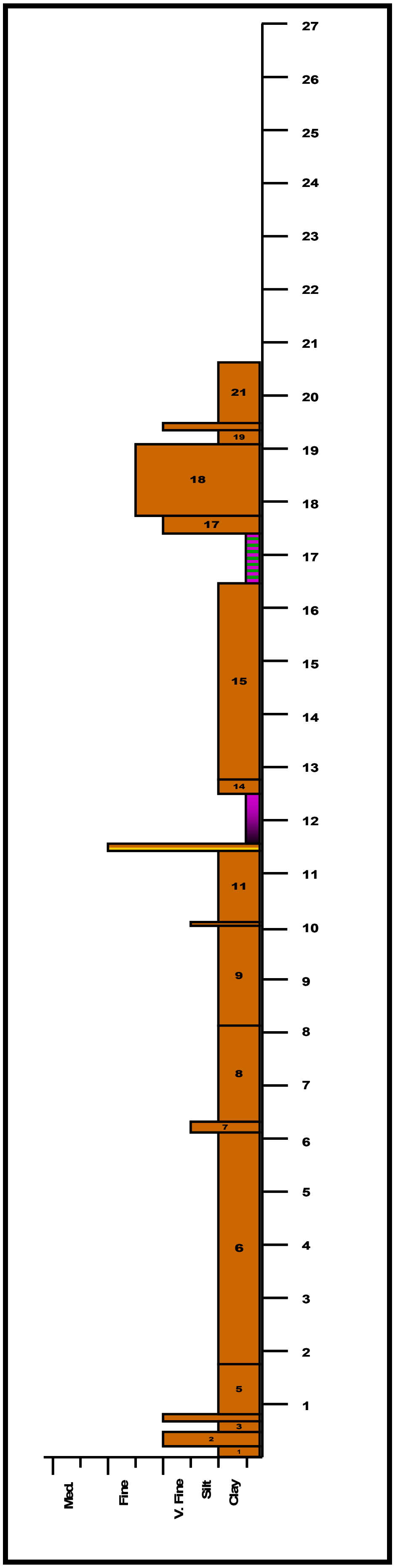


Fig 42 Data from core

Based upon the stratigraphic column (Fig. 2) and the correlations from the field guide book, the best look at how our observed facies changed throughout the basin would be from the Somerset #1 core. The Somerset coring sight is located ~ 60 miles from locations 1,2 & 3. A basin-wide correlation has been made using the Metlars Member of the Passaic (Olsen et al., 1996). The two largest black shale intervals persist in varying thickness throughout the basin. This section of the core is very different than any of the observed outcrops that belong to the Metlars or Livingston Members. Nearly the entire core is made up of silt-sized beds and intervening muds. Within the lower half of the section beds 2, 4, 7 10 and 12 stand out as extermely coarse grained perterbations in an otherwise homogenous silty grained succession of beds. Many of the same structures that are found at the other locations can be seen in core as well. Mudcracks, planar laminations, current ripples, carbonate nodules and evidence of bioturbation are all fairly abundant within this part of the core. The core can be divided into three sections divided by the two thick shale beds , 13 & 16. These are the two marker beds that have been established to correlate between the Somerset core and the Rutgers core and can also be seen in the measured sections for locations 1 and 2.

Bed #	Thickness (cm)	Lithology	Color	Grain Size	Sedimentary Structures
1	30	St	red	slt	
2	18	Ss	red	vfu	Sc PL RC TC
3	27	St	red	slt	Sandier interbeds in upper and lower sections
4	8	Ss	red	vfu	Sc TC
5	103	St	red	slt	CN
6	412	St	red	slt	CN VB HB
7	12	Ss	Red/ tan	vfu	VB PL TC Sc DC
8	207	St	red	slt	CN Sc HB
9	164	St	red	slt	DC Sc RC
10	6	St	red	slt	CN HB PL TC
11	121	St	red	slt	CN
12	24	St/Ss	Black	Slt / fu	CN upper 2 cm is composed of fine upper sand
13	97	Ms	Black/ purple/ red	c	PL RC DC
14	30	St	red	slt	
15	414	St	Red	slt	CN WL TC VB RC PL Purple horizon ~1/3 way of the way up from the base.
16	85	Ms	Black /red /green	c	Laminated VB
17	24	Ss	red	vfu	CN PL MC
18	55	Ss	Red/ tan	fl	RC CN VB
19	25	St	red	slt	RC CN
20	12	Ss	red	vfl	RC VB
21	73	St	red	slt	Sc PL TC CN
22					

Table 5 Data from core section

Key Structures

Fig 43 Mudcrack, mudchip and laminated mud from top of bed 12

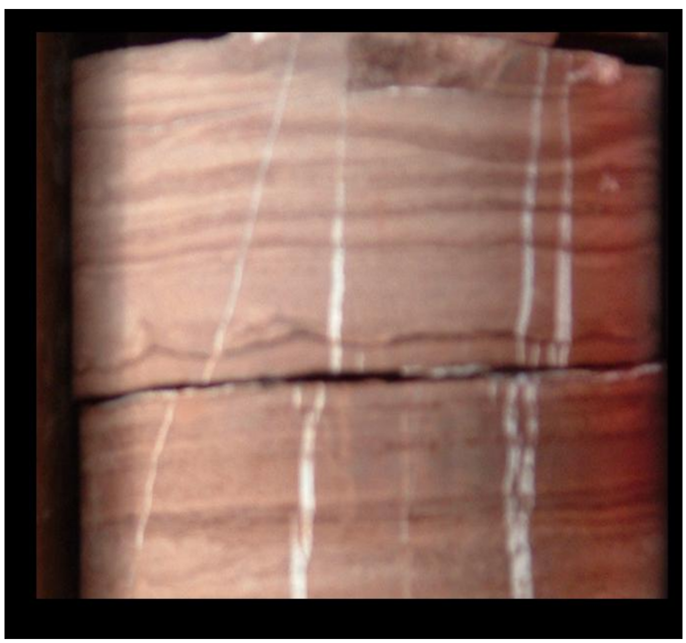


Fig 44 Current ripples, scour and soft sediment deformation from within bed 7.

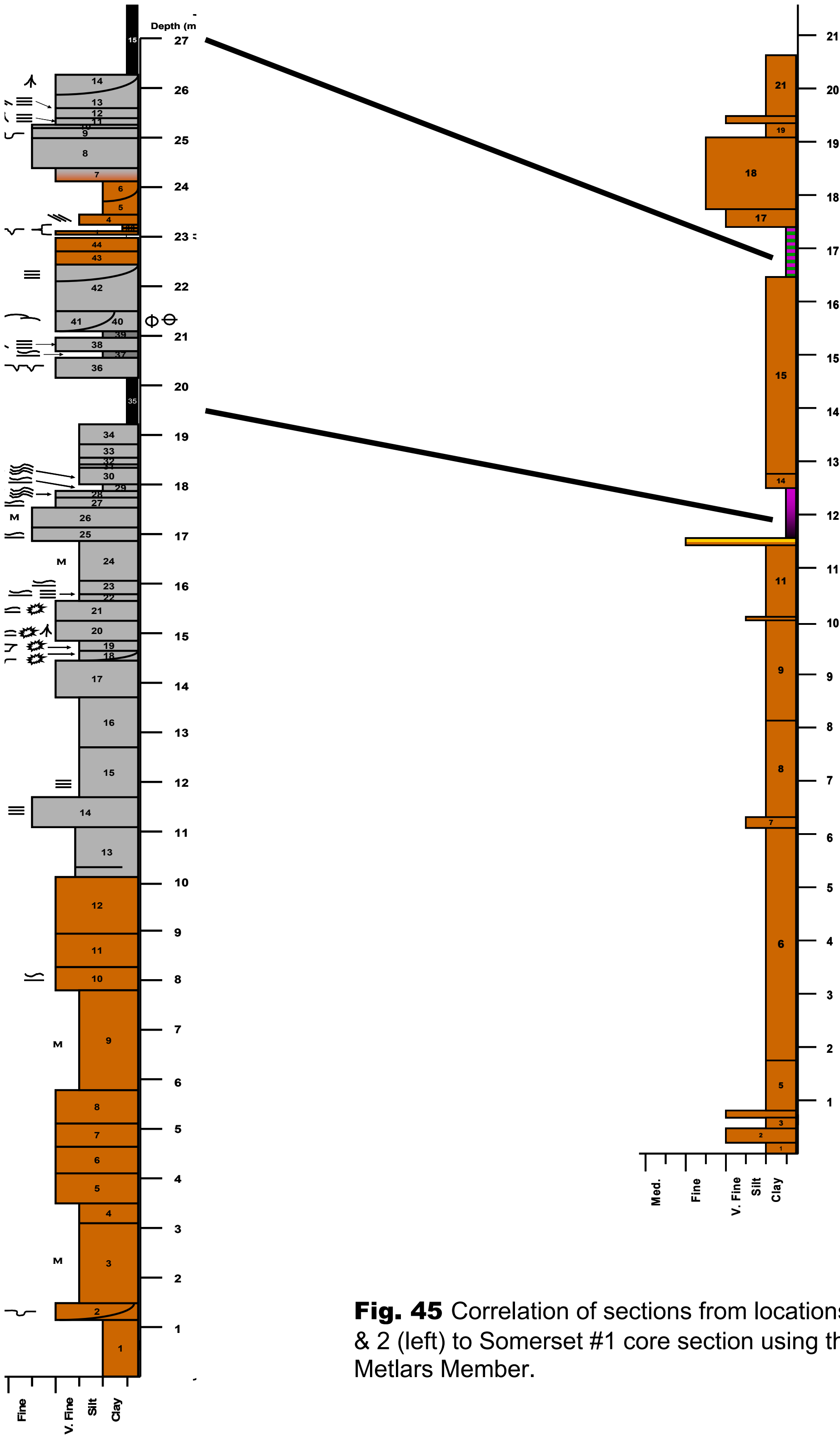


Fig. 45 Correlation of sections from locations 1 & 2 (left) to Somerset #1 core section using the Metlars Member.

5.6 Analysis of Uncertainty

The uncertainty that is associated with this project can be divided into two categories; error in data collection and error in interpretations made from the data. The error for each element of the measured sections is discussed in section 4.1 at the end of every description. The data descriptions includes how they were collected and any possible margin of error. The margin of error for the collection of grain sizes varies from 37μm up to 590μm because true grain sizes are grouped together in categories within which a range of sizes is possible. The measurement of bed thicknesses has a range of 0 – 10 mm. Bed thickness is measured using a tape measure which is divided into meters, centimeters and millimeters. Only the centimeter and meter divisions were used in measurements.

The next most obvious part of this research that is likely to contain a degree of uncertainty is the interpretation of field data. The scale of interpretation varies from the interpretation of sedimentary structures to the interpretation of the entire outcrop. The way in which I tried to limit this margin of error is through research in areas related to the subject at hand. This included literature on the Newark Basin, anastomosed fluvial systems, braided fluvial systems, ancient anastomsed systems, lacustrine systems, general sedimentary topics and other types of facies interpretations. Because of the significant contribution of data concerning Newark Basin research that was contributed by the Newark Basin Coring Project, a lot of relatively new material is available on the subjects of basin stratigraphy and lacustrine cyclicity within the basin. The recognized record of ancient anastomosed systems is limited but papers on ancient systems in Canada and Utah proved to be most helpful in narrowing down certain characteristics.

6. Discussion of Results

6.1 Interpretations

Railroad Cut (Location 1)

The record of three different depositional environments can be found at the outcrop at this location; lacustrine deltaic, deep water lacustrine and fluvial systems.

This entire outcrop has been previously interpreted as being deposited in deeper lakes, lake deltas and shallower lakes[1]. The lowest part of this outcrop (beds 1- 16 or 17) appears to be consistent with lacustrine deltaic deposition. The beds are mostly massive which usually occurs when sediment is deposited so rapidly that no sedimentary structures are preserved (Tucker, 1996). The base of bed 2 shows some degree of scour which would also seem to be consistent. Beds 14 and 15 contain planar bedding which is consistent with relatively high current velocities, which are also consistent. The lack of intervening deep-water shales is conspicuous. Marine and non-marine deltaic systems are usually composed of graded sand beds containing structures consistent with deposition in deccelerative flow such as planar laminations, current ripples and massive bedding. These sandbeds are interbedded with deep water shale deposits. The lower beds at this location are separated from the nearest shale bed by ~18 meters. The beds are very thick compared to thin sand/silt beds that are found in deltaic deposits (Prothero & Schwab, 1996). Bed 35 consists of ~ 1 meter of deep lacustrine shales. The unit at this location is the lowest of the two shale beds from the Metlars Member.

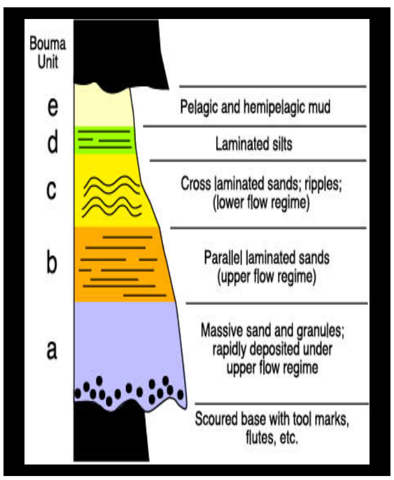


Fig 45 Typical succession of facies found in deltaic turbidity currents (turbidites) adapted from Drake & Lyttle 1981

The rest of the beds at this location consist of sharp based, tabular sandstones that are consistent with deposition in crevasse or terminal splay facies of fluvial systems. This part of the outcrop contains very few thick shale or mud deposits (with the exception of bed 35) , however, most sandbeds are draped in thin mud veils.. The mud beds that do exist are thin (2 – 6 cm) and are topped by very low amplitude, short wavelength unidirectional current ripples (fig 21 a) which are indicative of submersion in shallow, weak current water bodies following deposition (Nadon, 1994). The weak current water body could be the floodpond facies associated with crevasse splays (fig 10). Most of the sand beds in the upper part of the

[1] Interpreted by Joseph Smoot based on a discussion following the presentation of this material at the 2004 NE/SE regional GSA conference.

outcrop have wave rippled surfaces similar to those of the muddy beds and can be interpreted as coming from the same source. Climbing current ripples and planar laminations are structures associated with deposition in rapidly decelerating flow as would be found in crevasse deposits (Nadon, 1994). Bed 41 is probably the best example of structures like these. It has a scoured base (high current velocities) climbing ripples (depositing large amounts of coarse sediment), planar laminations and is capped by a thin layer of mud that has surface current ripples (fig 21 e). The frequency of occurrence of these structures and the overall geometry of the beds suggest stacking of crevasse splay sandsheets. Several beds also contain mudcracks indicating subaerial exposure. There are two primary means by which fluvial channels cam be stabilized; extensive fine grained, cohesive floodplain deposits and the reinforcement of levees by plant roots. At this location both parameters are met. The entire outcrop is predominantly silt and fine sand and root casts occur in bed 20 and in the beds of the overlying quarry at location 2. Climbing ripples and planar laminations suggest deposition in a position that is relatively proximal to the main channel and the lack of channelization in these deposits is consistent with the model for anastomosed systems, compare the the highly channelized deposits of braided and meandering systems. The fining upwards cycles exhibited by beds 20 -24 and again by beds 25 – 34 could represent limited lateral channel migration and backstepping of crevasse lobes leading up to the deep lake flooding represented by the shales in bed 35. The presence carbonate nodules is again evidence for deposition in very shallow water as they form primarily as soil horizons in semi-arid climates (Tucker, 1996).

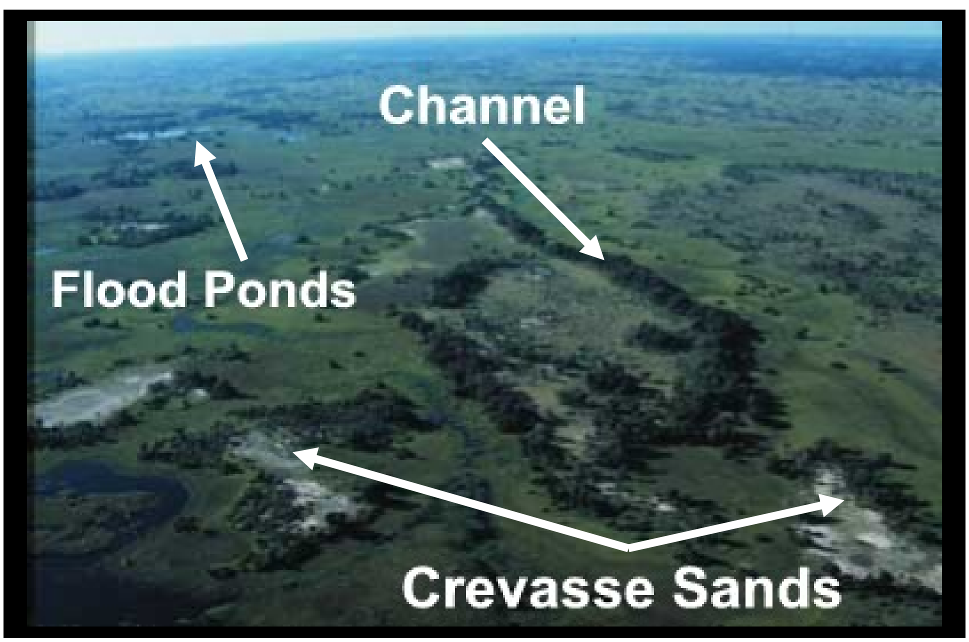


Fig 46 Anasotmosed floodplain of the Okavango River, Botswana. Adapted from photo taken from web (lost citation)

Roadside Quarry

The uppermost bed at this location is a ~1.5 meter bundle of deep water lacustrine shales (Olsen & Gore, 1989) and marks the upper of the two basin wide shale packages that define the Metlars member of the Passaic. The rest of the outcrop isn't as clear cut. The base is made up of thin red beds that show good evidence of exposure (mudcrack) indicating that they were deposited in very shallow, ephemeral lacustrine or floodpond environments (fig.25 a). The rest of this outcrop is made up of beds that are not all that dissimilar from the lower beds of the location1. They are thick bedded and massive with most sedimentary structures localized within beds 9, 10 , 11 and 12. These central beds somewhat resemble the crevasse sands of location 1. They are rooted, rippled and planar laminated. Bed 9 has a gently scoured base.

Trap Rock Quarry

. The sand beds here are very tabular with sharp bases. The scour in bed 3 is the best candidate for an anastomosed floodplain channel. There is abundant for rooting and soil development (carbonate nodules) suggesting shallow water depths along with current ripples, planar laminations and rip up clasts suggesting a fluvial environment. Much like the first two locations, no channels are evident that show evidence of lateral accretion.

Pebbles Bluff

The rocks at Pebbles Bluff are very different from all the other locations. This outcrop didn't help to make the case for the existence of anastomed systems within this part of the basin, but, it did provide a context for how several other significant depositional facies appear.

The upper Pebbles Bluff contains deposits of braided fluvial systems (fig 32), alluvial fans and shallow lacustrine silts and muds. The lower part of the outcrop at this location ,the part that has been measured for this project, can be divided into three distinct categories based on depositional environment. Listed from bottom to top they are:

1. Meandering Fluvial
2. Shallow Lacustrine
3. Lacustrine Deltaic

The meandering fluvial facies is defined by the presence of large scale lateral accretion surfaces (epsilon crossbeds). These are diagnostic of channel processes within meandering fluvial systems. The individual beds that define the crossbed structures are comparatively coarse grained (vfu – ml) (fig. 33). Internally they are massive and some are capped by surface ripples. No distinct lensoidal channel cross section is seen at this location but the lee side of the lateral accretion surfaces indicate that one may be present further to the south and may be covered. The lateral accretion surfaces are underlain by planar bedding as well.

Fig 47 Lower Pebbles Bluff outcrop showing interpretations

The middle of this part of the outcrop (bed 16) consists of centimeter scale mud bed that each show evidence of subaerial exposure in the form of Mudcracks. These red muds are similar in nature to beds 1, 2 and 3 of location 2 but are finer grained and thinner bedded (fig 34 a). This represents a slightly deeper facies than the fluvial facies below and was most likely deposited in very shallow ephemeral lakes.

The upper part of the outcrop (beds 17- 29) is defined by two fining-upwards cycles within which are thinner beds containing repetitive series of structures. The base of this portion is defined by sharp basal scour and graded scour fill (bed 17, fig 34b). The succession of structures, scour → massive bedding → Planar laminations -→ current ripples is consistent with deposition by turbity currents(fig 45). In a lacustrine environment these occur within deltaic complexes.

Based on these interpretations, the outcrop at location 4 represents an overall deepening upwards succession of facies.

7. Suggestions for Future Work

There are numerous exciting possibilities for future work in the area fluvial basin studies within the Newark and the Newark Supergroup as a whole. These fluvial deposits make up a significant portion of many the deposits within the Newark Basin, and as such, should be incorporated into present models for the cyclical deposition of basin fill facies. Some possible work includes:

- Further description and interpretation of fluvial deposits within the Passaic.
- Correlation of fluvial depositional styles to patterns of lacustrine cyclicity.
- Use of data derived from lacustrine cycles to coincide such parameters as paleoclimatic and paleotectonic change to fluvial evolution and development.
- Complete model of VanHouten cycle deposition by filling in the upper “fluvial” component. Cycles are subdivided based upon relative lake depth; maybe there is a pattern between lake depth and particular fluvial facies and/or succession of facies.
- Incorporate all previously listed data and interpretations into a complete, comprehensive model for rift basin evolution.

8. Conclusions

Outcrop and core locations for this project were carefully chosen to represent the deposits of the Passaic Formation on a basin wide scale. The deposits show a high degree of temporal and spatial diversity from one location to another. It has been shown that the majority of the fluvial deposits that have been documented do not display characteristics that are consistent with deposition in braided or meandering fluvial systems. Evidence of these fluvial styles were found only in areas that were proximal to regions of highest relief at the time of their deposition (them main border fault system at pebbles Bluff). The lack of channelization, abundance of fine grained sediment, abundance of crevasse splay sandsheets, occurrence of ephemeral lacustrine deposits, low relief channel forms as well as the presence of rooted horizons that would have provided for channel stability suggest deposition in an anastomosed fluvial system at location 1. Anastomosed systems do occur within the coarse grained facies of the Passaic Formation and have been observed in this project.

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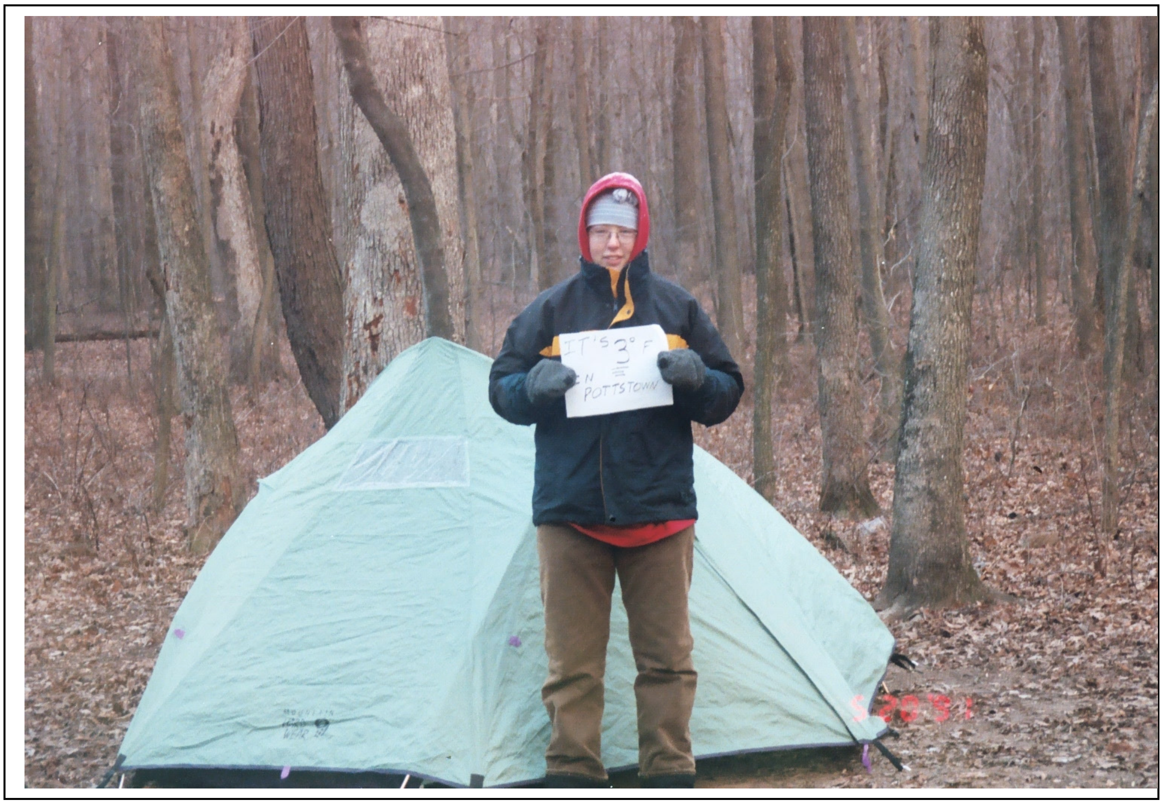
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